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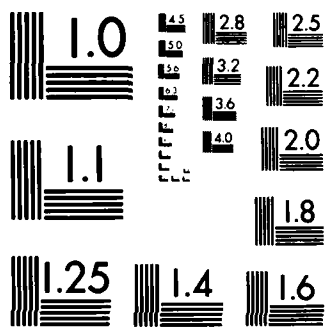

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Cheyenne Mountain Late Time Simulation Results

K. HAIN, G. HAIN AND J. A. FEDDER

Geophysical and Plasma Dynamics Branch
Plasma Physics Division

June 7, 1985

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In this report we present results for the late time evolution of the Cheyenne Mountain nuclear explosion scenario. Results are presented from both the DEMAG simulation code and the MELT simulation code. The results are compared and the differences between them are explained. We conclude that the simulation results are in good agreement.

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CHEYENNE MOUNTAIN LATE TIME SIMULATION RESULTS

I. INTRODUCTION

The Cheyenne Mountain nuclear detonation scenario involved a high altitude (> 150 km), large yield (> 1 M ton) nuclear explosion over the central Rocky Mountain region of the U.S. Such high altitude nuclear explosions (HANE) evolve through a number of temporal stages during which the physical description of the explosion and the effects are radically different from each other. For the simulation results presented in this report we are concerned with the last and longest period of evolution of a HANE; a period, hours in length, when the vast amount of plasma created in the explosion slowly evolves, and the ionosphere and magnetosphere return to their pre-burst condition.

The computer codes which have been developed to study the period are commonly termed "late-time electrostatic codes". There are two of these codes: the NRL code DEMAG and the MRC code MELT. The codes are "late time" because they simulate HANE phenomenology later than about 5 min after detonation. They are termed "electrostatic" because plasma motion perpendicular to the geomagnetic field is treated in terms of an electrostatic potential field. The theory for the perpendicular plasma transport for the DEMAG code has been reported in Hain and Fedder (1984). The theory for the parallel plasma transport is the usual hydrodynamic theory. The theory for the MELT code has been previously reported in Longmire and Kilb (1977) and Kilb (1977).

In this report we will discuss and compare the two codes DEMAG and MELT which use very different algorithms. We will show results of simulations from each code for the Cheyenne Mountain scenario during the

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temporal period of 5 to 30 minutes after burst. We will discuss the results pointing out similarities and differences between them. Finally we will briefly summarize these results and present our conclusions.

II. CODE DESCRIPTION

Although both codes, DEMAG and MELT, are designed to solve an identical set of theoretical equations, the numerical algorithms used are considerably different. The DEMAG numerical algorithm used for both neutral atmosphere and plasma transport is an "Eulerian" algorithm; the numerical grid is a constant fixed mesh. Both the plasma and the neutral gas are transported across the grid from mesh point to mesh point. The MELT code uses a "Lagrangian" algorithm for the plasma transport. That is, as plasma is transported from point to point in space, the numerical mesh points are moved along with the plasma and the same parcel of plasma remains within the same numerical cell. The neutral atmosphere in the MELT code uses a fixed "Eulerian" mesh as does the DEMAG code.

Figures 1 and 2 show the DEMAG fixed meshes for the plasma and the neutral gas, respectively, on a geomagnetic meridional plane in the Northern hemisphere. For the plasma (Fig. 1) the coordinate lines are magnetic field lines and magnetic potential lines. For the neutral gas (Fig. 2) the coordinate lines are an adapted coordinate system which tends toward a magnetic orientation at high altitudes and is spherical at low altitudes; the coordinate system is described mathematically in Appendix A. In each case the third coordinate is the rotational coordinate about the magnetic axis. Figure 3 is a similar diagram to Fig. 1 except it shows the MELT plasma mesh. Here one can clearly see the magnetic field line coordinate but the coordinate along the field is unequally spaced and is controlled by the motion of plasma along the field line. The MELT neutral atmosphere mesh is an earth centered spherical mesh which terminates at 1500 km altitude and is not shown here.

The choice of numerical meshes for the simulations is controlled by a number of considerations. The spherical nature of the neutral atmosphere at low altitudes is required to allow the burst disrupted atmosphere to return to a sensible hydrostatic equilibrium. The distortion of the DEMAG neutral mesh at higher altitudes towards a geomagnetic mesh is designed to allow a better description of neutral gas motion as it is carried to high altitudes by the plasma.

Both codes, DEMAG and MELT, make use of a geomagnetic field aligned mesh for the plasma owing to consideration of the electrostatic nature of the plasma transport at late times. For electrostatic plasma transport the magnetic field is considered to be constant. Moreover, plasma motion perpendicular to the field has a very special property; specifically, all plasma on a common field line (more correctly contained in a common flux tube) at a particular moment of time remains on a common field line (in a common flux tube) for all time. The plasma is said to be "frozen" to the field. A geomagnetic field line coordinate therefore is a natural choice for the plasma mesh.

The DEMAG choice of "Eulerian" transport on the geomagnetic mesh involved two considerations. First, it was felt that modern numerical methods were sufficiently accurate to adequately control numerical errors and to maintain a good approximation to the field frozen plasma motion described above. Second, Eulerian transport is inherently simpler in multiple dimensions because of the fixed numerical grid, and in such large codes, simplicity is an advantage where obtainable. The MELT code has the advantage that the Lagrangian transport exactly satisfies the field frozen plasma motion until the numerical grid becomes too distorted for further computation. At this point the grid must be restructured which is a complex and difficult operation, and to some undetermined extent violates the field frozen condition thereby partially negating its initial advantage.

Clearly there are many possible choices to be made when developing simulation codes as complex and difficult as DEMAG and MELT. Different people will make different choices and all for good reasons. It is therefore not too surprising that two very different codes have been developed to simulate the same types of HANE problems. The quality of the codes and the different approaches can only be tested by comparing simulation results to data. In the absence of hard data, which is almost non-existent for late time HANE, the quality of simulations can only be verified by comparing results from different codes. In the case of two very different codes such as DEMAG and MELT such a comparison of results can provide a verity to the results which would otherwise be totally unattainable.

III. RESULTS

In this report we show results from both the DEMAG and MELT simulations for the Cheyenne Mountain HANE scenario for the time period 300 to 1800 seconds after burst. The two simulation codes where initialized at 300 seconds with the same data set which was generated by MRC with the MICE MHD nuclear simulation code.

At 300 sec the initial blast wave from the burst has propagated far from the burst point. The large cavity in the geomagnetic field has collapsed and the magnetic field has returned to ambient values. The remnant of the HANE is a large, geomagnetic field aligned plume of plasma which extends from the northern conjugate to the southern conjugate ionosphere. The lower portion of this plasma plume with plasma densities greater than 10^8 cm^{-3} is shown in Figs. 4 and 5. The plasma in the plume is moving at high velocities along the field lines in order to achieve a hydrostatic equilibrium and at lower altitudes in response to strong upward neutral atmospheric heave winds. The still highly disturbed neutral atmospheric densities are shown in Figs. 6 and 7. The geomagnetic field lines which contain the plasma plume pass through the equatorial plane of the magnetosphere at altitudes above one earth radius. Figure 8 which shows a contour diagram of the field line integrated densities at the geomagnetic equator shows the great size of the plasma plume at high altitudes. It is more than 2000 km in width and 4000 km in depth perpendicular to the geomagnetic field.

During the simulation the plasma in the geomagnetic field aligned plume evolves. It loses density via recombination at low altitudes in the ionosphere. The plasma moves up and down along the field lines in response to pressure and gravity forces, and also in response to the neutral atmosphere heave winds. Motion of the plume perpendicular to the geomagnetic field occurs due to gravity forces, centrifugal forces, coriolis forces, and neutral wind friction forces. The motions along the field and recombination slowly deplete the plume plasma density, while motions perpendicular to the field distort and stretch the plume onto higher latitude flux tubes or compress the plume onto lower latitude flux tubes. The plume can also drift slowly relative to the earth's rotation.

The cumulative effects of these processes on the plasma plume can be seen in Figs. 9-11 while the relaxation of the neutral atmosphere to near ambient density is seen in Fig. 12. In studying the plasma density in Figs. 9 and 10 it is noted that the maximum plasma density in the plume has fallen by about a factor of 3 in one half hour. The plume has moved poleward (northern plume northward - southern plume southward) about 600 km. Moreover, the poleward border of the plasma plume is more diffuse and has a considerably reduced density gradient. A better picture of the poleward motion can be seen by comparing the result in Fig. 11 with the initialization in Fig. 8. In this comparison it is seen that the eastward and westward portions of the plume plasma has remained almost stationary while the center has moved upward in the equatorial plane. The motion in the ionosphere is similar. The eastward and westward portion of the plumes remain almost stationary while the center of the plume moves poleward. A comparison of Figs. 9-11 shows that the field frozen plasma motion results in higher velocities at high altitudes. As the plume moves 600 km poleward in the ionosphere the equatorial portion of the plume moves 3000 km higher.

Figures 13 and 14 show MELT results for the plasma density at 1800 secs; they are to be compared to Figs. 9 and 10 of the DEMAG results. One first notices that the maximum plasma densities in the two sets of results are very nearly the same, and that both plasma plumes appear to be decaying in a similar manner. There are, however, some differences. The poleward density gradient in the MELT results is much sharper than in DEMAG. This difference could be a result of the different numerical algorithms, that is, a result of the Eulerian algorithm in DEMAG allowing more diffusion across the geomagnetic field; or it could be the result of the more evolved poleward plume motion in DEMAG. The DEMAG plasma plume moves about twice as far poleward as does the plume in the MELT simulation. The difference in poleward motion of the two plumes will be discussed more fully later as it appears to be the major difference between the simulation results.

Comparisons between the results of the simulations for other plasma and atmospheric properties can be carried out by using the microfiche. The fiche contain plasma and neutral densities, pressure, and temperature; species densities; and plasma and neutral motions. The DEMAG results are shown starting with initial conditions at 300 sec intervals between 300 and 1800 sec. The MELT results are shown at 600 sec intervals between 600 and 1800 secs. A description of the fiche figures and layout is contained in Appendix B.

IV. DISCUSSION

The DEMAG and MELT results shown on the fiche have been compared to each other between 600 and 1800 sec. The comparison of data shows an overall agreement between results, particularly if one is interested in the high plasma density regions of the plume. Results for plasma and neutral densities, temperatures and species densities are all very similar and are approximately equal. The primary difference between the results involves the poleward and upward motion of the plume. The DEMAG plume moves faster and about twice as far poleward as the MELT plume. We think this difference in motion perpendicular to the geomagnetic field has a straightforward explanation which follows.

In both DEMAG and MELT the primary forces driving plasma motion perpendicular to the geomagnetic field are neutral drag, caused by atmospheric heave and relaxation; centrifugal forces, caused by rapid plasma motion along the curved geomagnetic field in the plume; and gravitational attraction, pulling the plasma plume downward and equatorward. For the Cheyenne Mountain simulation these three forces are initially in a very sensitive balance: the neutral drag and centrifugal forces pushing upward, and gravity pulling downward. If either of the codes emphasizes or diminishes one of these forces relative to the other code, we would expect a difference in motion owing to alterations in the sensitive balance of the driving forces.

Figures 15 and 16 show potential plots for DEMAG and MELT, respectively, at 600 secs. Plasma flow is along the potential contours perpendicular to the geomagnetic field. The potential contours are shown on the geomagnetic equatorial plane. The reader will notice immediately that the contours near the boundaries in the two figures are decidedly different. The difference arises due to different boundary conditions for DEMAG and MELT but are not significant to the results since motion in these regions involves only incompressible flow of almost uniform ambient background ionosphere. Near the center of the plots the flow lines are much more similar.

The DEMAG results (Fig. 15) show three different regions of flow in the plasma plume. Between 6000 and 8000 km altitude there is strong upward flow near the center plane of the plume. The upward flow turns outward and then downward near the edges of the plume. This region of flow is driven by a local dominance of the centrifugal force term. At higher altitudes between 9,000 and 11,000 km the flow throughout the central portion of the plume is downward. This downward flow region is driven by a local dominance of the gravitational force term. Finally, in the highest portion of the plume, between 11,000 and 14,000 km, the flow near the central plane is again upward and is controlled by a local dominance of the neutral drag force term. (The neutral drag does not occur at these equatorial altitudes but takes place at the poleward border of the plume at lower altitudes.)

Similar flow features can be seen in the MELT results (Fig. 16). The low altitude upward flow occurs between 5500 and 7500 km altitudes. The downward flow occurs throughout the central portion of the plume between 8000 and 11,000 km. Above 11,000 km the downward flow is substantially weakened, where the DEMAG results show upward flow. These results can possibly be seen more clearly in the velocity vector diagrams shown in Figs. 17 and 18 for DEMAG and MELT, respectively.

The primary areas of disagreement in these results relate to the absence of upward flows at the highest altitudes in the MELT results and to the faster downward flow in the central plume shown in the MELT results relative to those of DEMAG. The reason for these differences is shown in Figs. 19-22.

Figures 19 and 20 show the neutral atmospheric densities on the central meridional plane at 600 sec for both the northern and southern conjugate regions. Of particular interest is the large atmospheric density above 1500 km altitude (the top of the MELT neutral grid) which occurs in both hemispheres. The high neutral density, because of its great extent along the geomagnetic field, can be very effective in enhancing the neutral drag force term in DEMAG relative to that in MELT. Figures 21 and 22 show that the neutral velocities at these high altitudes are primarily upward and poleward relative to the geomagnetic field, and therefore the enhanced neutral drag force term would strengthen upward and poleward plume motion. Since this force occurs at altitudes above 1500 km the MELT results do not account for it and therefore the MELT plume experiences less poleward acceleration. Increasing the MELT neutral atmospheric grid to roughly double its present height would be expected to bring the results into much closer agreement.

At 1800 secs, Figs. 23 and 24 show potential contours and Figs. 25 and 26 show velocity vectors for DEMAG and MELT, respectively. At this late time the plasma plumes in both results are moving primarily upward and poleward. The DEMAG plasma which began moving poleward earlier and more strongly continues to move slightly faster. This continuing difference in the results can again be traced back to the more dominant neutral drag force than in the DEMAG simulation at earlier times. At this time, the centrifugal force term is dominant and is forcing the upward and poleward motion. As the plasma motion in the plume parallel to the geomagnetic field slows and relaxes, gravitational forces will eventually dominate and will then cause the plume to fall and move equatorward. Since the DEMAG plume moves further poleward the DEMAG results indicate a more lengthy return to equilibrium than do the MELT results. More complete analysis of the complex perpendicular motion and the delicate balance of forces can be undertaken by study of the fiche entitled "POT". The fiche show potentials, velocities and force terms for the DEMAG simulations. The "POT" fiche are described in Appendix C.

In summary, we would conclude that the DEMAG and MELT simulations of the Cheyenne Mountain scenario are in good agreement. The primary disagreement involving perpendicular motion is understood and has been explained. We have also discussed the implications of that disagreement for later time evolution of the plasma plume. Both codes DEMAG and MELT appear to provide reasonably accurate results for the late time evolution of a high altitude nuclear explosion.

ACKNOWLEDGMENT

This research has been supported by the Defense Nuclear Agency.

Appendix A

This appendix discusses the derivation of the NRL DEMAG coordinate system for the neutral atmosphere. For reasons discussed in the text, this coordinate systems tends to dipolar magnetic coordinates at high altitudes and tends to a spherical coordinate system at low altitudes.

We consider a function of $f(y, r, \theta) = 0$ where y is a coordinate line description, r is the geocentric radius normalized to the earth radius and θ is the geomagnetic colatitude. Moreover, we require f to be a monotone function of r and θ, for η positive. The unit vectors perpendicular to η are given by

$$e_r = \frac{\partial f}{\partial r} \Big/ \sqrt{(\partial f/\partial r)^2 + (1/r\ \partial f/\partial\theta)^2}$$

$$e_\theta = \frac{1}{r}\frac{\partial f}{\partial\theta} \Big/ \sqrt{(\partial f/\partial r)^2 + (1/r\ \partial f/\partial\theta)^2}.$$

We now require that

$$e_r = 0 \text{ at } r = 1 \text{ (earths surface)}$$

$$e_\theta = 0 \text{ at } \theta = \frac{\pi}{2} \text{ (magnetic equator)}$$

A simple function which satisfies these conditions is

$$f = \frac{(r - 1)^\varepsilon}{(\eta - 1)^{\varepsilon - 1}} - (\eta \sin^2\theta - 1) \text{ for } \varepsilon > 1.$$

For $\varepsilon = 1$, f describes a dipolar coordinate line; whereas for $\varepsilon = \infty$, f describes a radial coordinate line. For the DEMAG neutral mesh, we use $\varepsilon = 2$.

To numerically generate the grid we construct a coordinate line through the burst point and compute its total length. We subdivide this coordinate line to obtain one set of coordinates and then construct an orthogonal mesh to each side of this base coordinate line. The resulting mesh is displayed in figure 2.

The neutral boundary conditions are reflecting at 100 km altitude and out-flow on the other boundaries.

Appendix B

Tables B1 and B2 show the layout of the plots on the microfiche for the DEMAG and MELT results, respectively. The NRL fiche show the DEMAG results at 300 sec intervals between 300 and 1800 sec. The MRC fiche show the MELT results at 600 sec intervals between 600 and 1800 sec.

The quantities N_e, $v_\perp$, and Ψ are the field line integrated density, the perpendicular to B velocity and the electrostatic potential, respectively, plotted on the geomagnetic equatorial plane. n, P, and T are the density, pressure, and temperature, respectively. (N), (S), and (V) indicate the northern conjugate, southern conjugate meridional plane, and a vertical plane 5300 km north of the equator through the burst region and perpendicular to the central meridional plane. Subscripts e, p, i, N and v indicate electrons, plasma, ions, neutrals, and N_2 vibrational state, respectively.

Individual constituents enclosed in brackets, such as $[N^+]$ indicate species concentrations. A arrow, →, designates a vector plot and a star, *, signifies an expanded view of the burst and conjugate regions. A double star, **, indicates a unit vector plot to show flow directions. For the vertical plane velocities, v_x, v_y, and v_z show velocities in the meridional, longitudinal and vertical direction, respectively. For the MRC fiche a parallel, ∥, designates velocities parallel to the magnetic field.

All quantities are plotted in cgs units.

Table B1—NRL CHEYENNE

	$n_e(S)$	$T_e(N)$	$[O_2^+](S)$	$\overset{*}{n}_N(S)$	$T_n(S)$	$[N_2](N)$	$\overset{**}{\vec{v}}_n(N)$	$v_y(V)$
Title	$\overset{*}{n}_e(S)$	$T_i(S)$	$[O)_2^+(N)$	$\overset{*}{n}_N(N)$	$T_v(N)$	$[O_2](S)$	$\|v_N\|$	$v_z(V)$
Plasma grid	$\overset{*}{n}_e(N)$	$T_i(N)$	$[NO^+](S)$	$n_N(N)$	$[N](S)$	$[O_2](N)$	$n_N(V)$	$\|v_N\|(V)$
Neutral grid	$n_e(N)$	$[N^+](S)$	$[NO^+](N)$	$P_N(S)$	$[N](N)$	$[NO](S)$	$P_N(V)$	$\vec{v}_N(V)$
N_e	$P_p(S)$	$[N^+](N)$	$v_p(S)$	$P_N(N)$	$[O](S)$	$[NO](N)$	$T_N(V)$	
$\vec{v}_\perp$	$P_p(N)$	$[O^+](S)$	$\vec{v}_p(N)$	$T_N(S)$	$[O](N)$	$\vec{v}_n(S)$	$T_v(V)$	
Ψ	$T_e(S)$	$[O^+](N)$	$n_N(S)$	$T_N(N)$	$[N_2](S)$	$\vec{v}_n(N)$	$v_x(V)$	

Table B2--MRC CHEYENNE

	$n_e(S)$	$T_e(N)$	$[NO^+](S)$	$\overset{*}{n}_N(S)$	$T_v(S)$	$[N_2](N)$	$\overset{**}{\vec{v}}_n(N)$	$v_y(V)$
Title	$\overset{*}{n}_e(S)$	$T_i(S)$	$[NO^+](N)$	$\overset{*}{n}_N(N)$	$T_v(N)$	$[O_2](S)$	$\|v_N\|$	$v_z(V)$
Plasma grid	$\overset{*}{n}_e(N)$	$T_i(N)$	$[H^+](S)$	$n_N(N)$	$[N](S)$	$[O_2](N)$	$n_N(V)$	$\|v_N\|(V)$
Neutral grid	$n_e(N)$	$[N^+](S)$	$[H^+](N)$	$P_N(S)$	$[N](N)$	$[NO](S)$	$P_N(V)$	$\vec{v}_N(V)$
N_e	$P_p(S)$	$[N^+](N)$	$v_p^{\parallel}(S)$	$P_N(N)$	$[O](S)$	$[NO](N)$	$T_N(V)$	
$\vec{v}\perp$	$P_p(N)$	$[O^+](S)$	$v_p^{\parallel}(N)$	$T_N(S)$	$[O](N)$	$\vec{v}_n(S)$	$T_v(V)$	
Ψ	$T_e(S)$	$[O^+](N)$	$n_N(S)$	$T_N(N)$	$[N_2](S)$	$\vec{v}_n(N)$	$v_x(V)$	

Appendix C

The POT fiche show quantities related to the electrostatic potential equation. The organization of the fiche are shown in Table C1. The quantities presented are field line integrated and are shown on the geomagnetic equatorial plane. Various quantities are described by a series of letters which indicate their identity. First letters D, T, and F signify ion-neutral drag or friction forces: transport forces including the convective derivative, coriolis forces, and centrifugal forces; and body forces including the pressure gradient and gravity, respectively. The second letters P and H indicate Pedersen and Hall components, respectively. The subscripts 1 and 2 indicate the meridional and longitudinal components, respectively. The sum of the forces are signified by S1 amd S2 where S1 = DP2 + TP2 + FP2 + DH1 + TH1 + FH1 and S2 = DP1 + TP1 + FP1 + DH2 + TH2 + FH2. The symbol R shows the divergence of S. The symbols C and E signify the capacitance and conductivity matrices, respectively, with the subscripts indicating which matrix element.

The theory and derivations for the quantities in the POT fiche are fully described in Hain and Fedder (1984).

Table C1—NRL POT CHEY

	DP_2	TH_2	C_{11}
Title	TP_2	FH_2	C_{22}
Ψ	FP_2	S_1	C_{12}
$\vec{\nabla}_1$	DH_1	S_2	E_{11}
DP_1	TH_1	$\nabla_1 S_1$	E_{22}
TP_1	FH_1	$\nabla_2 S_2$	E_{12}
FP_1	DH_2	R	

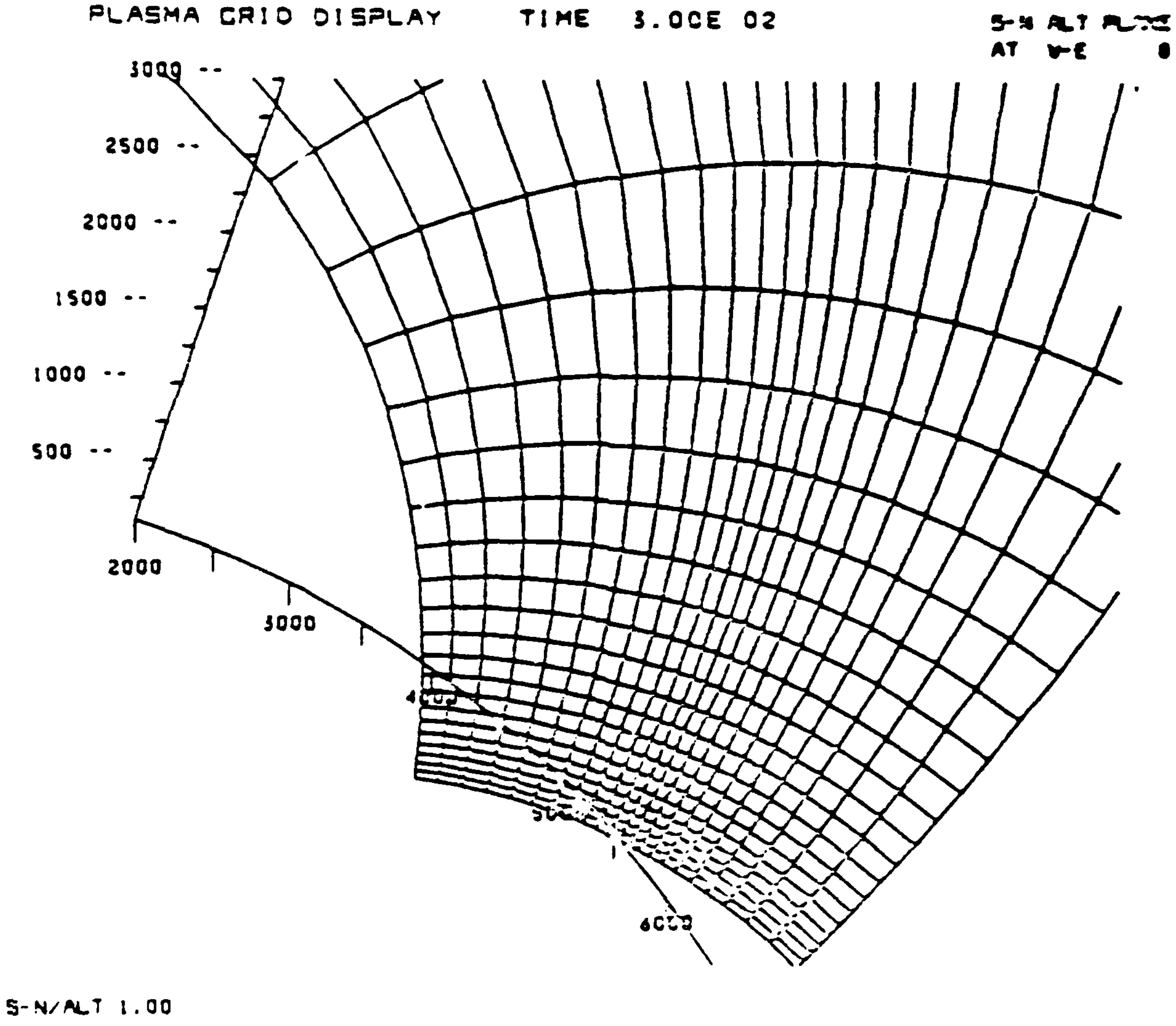

Figure 1. A plot of the geomagnetic field aligned plasma grid for the DEMAG code on a meridional plane in the northern conjugate region. The vertical scale is altitude and the horizontal scale is distance from the geomagnetic equator along the earth's surface in kilometers.

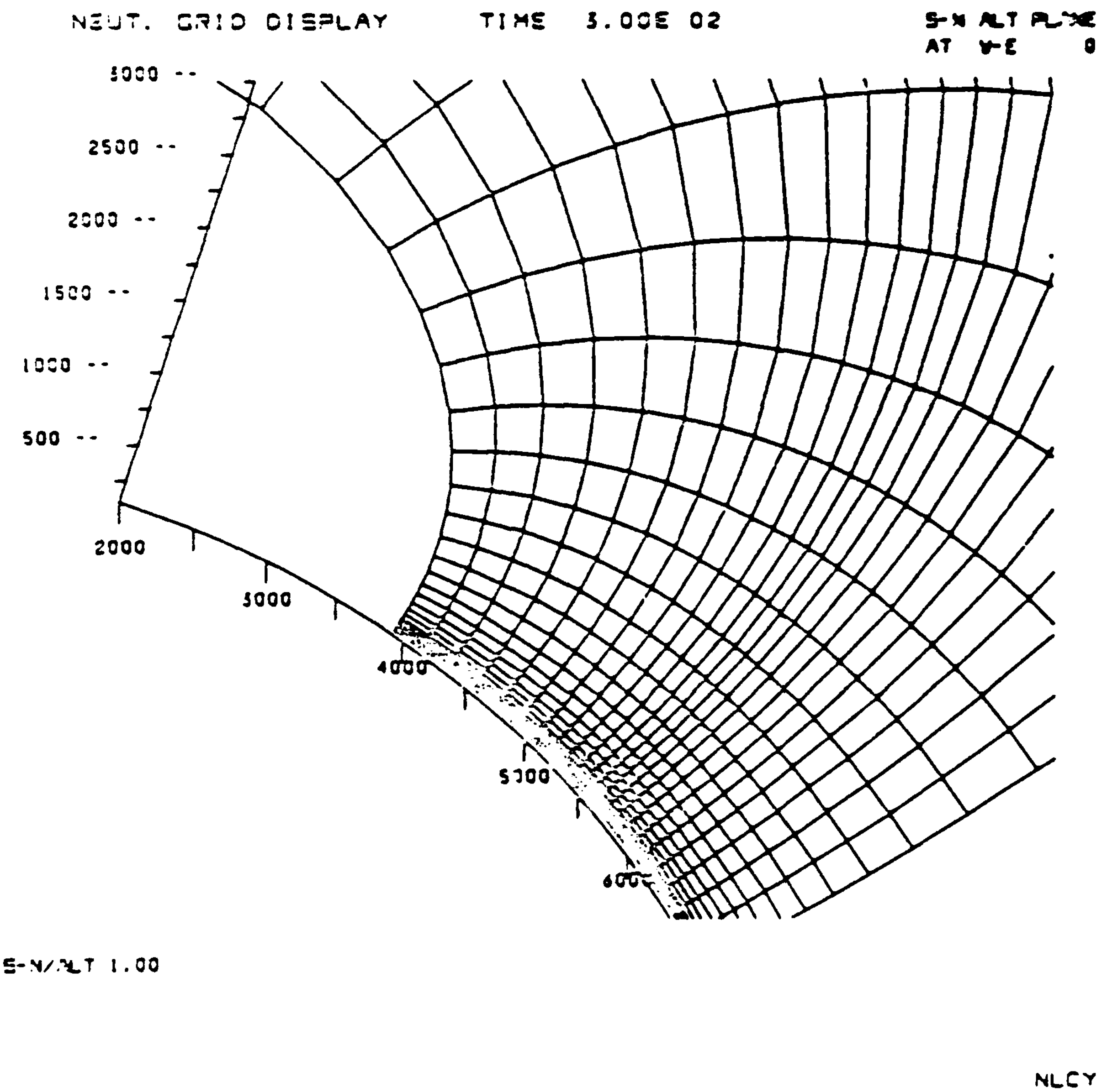

Figure 2. A plot of the neutral atmosphere grid for the DEMAG code on a meridional plane in the northern conjugate region. The vertical and horizontal scales are identical to those in Figure 1.

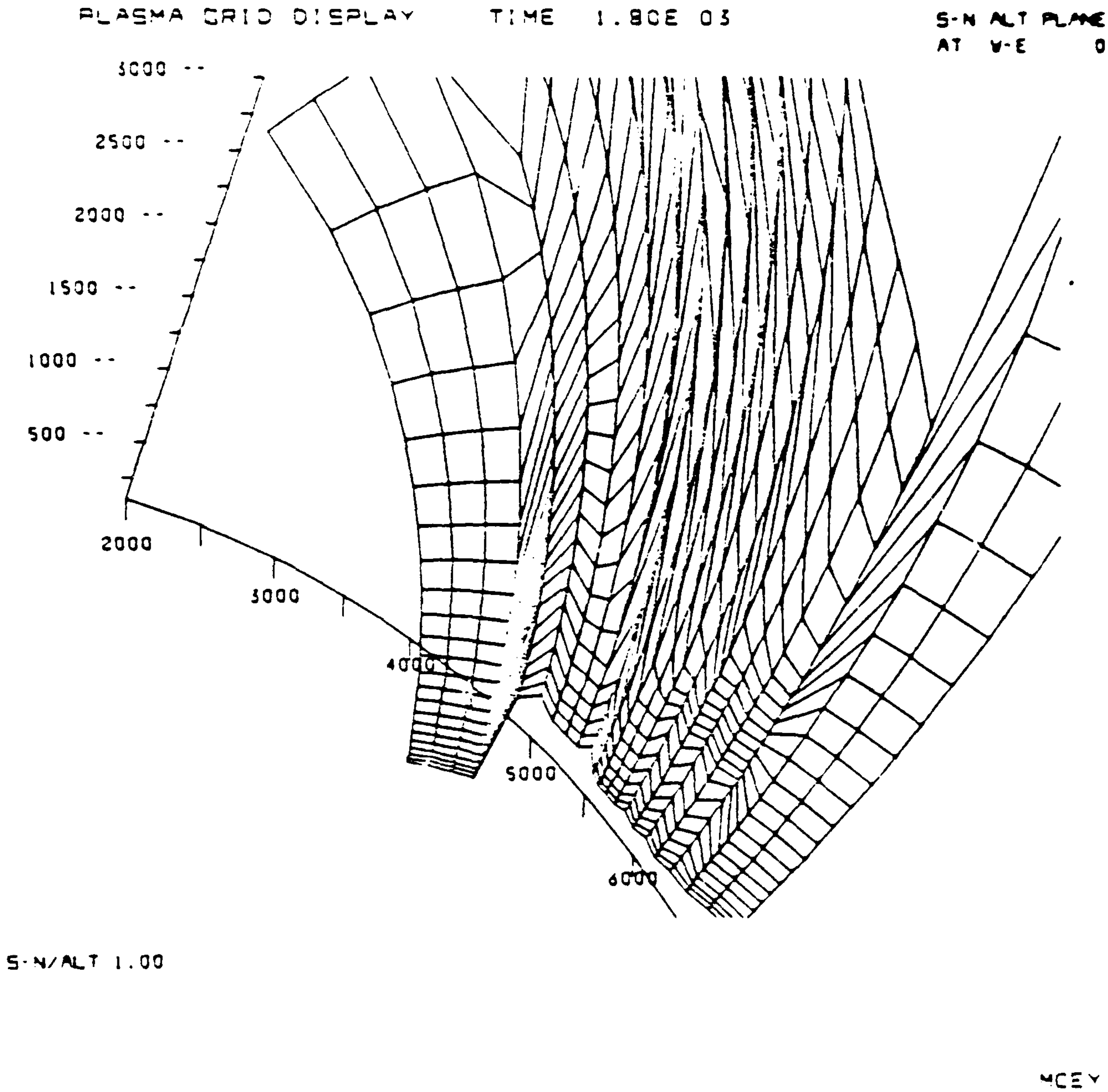

Figure 3. A plot of the "Lagrangian" geomagnetic field aligned plasma grid for the MELT code on a meridional plane in the northern conjugate. The vertical and horizontal scales are identical to those in Figure 1.

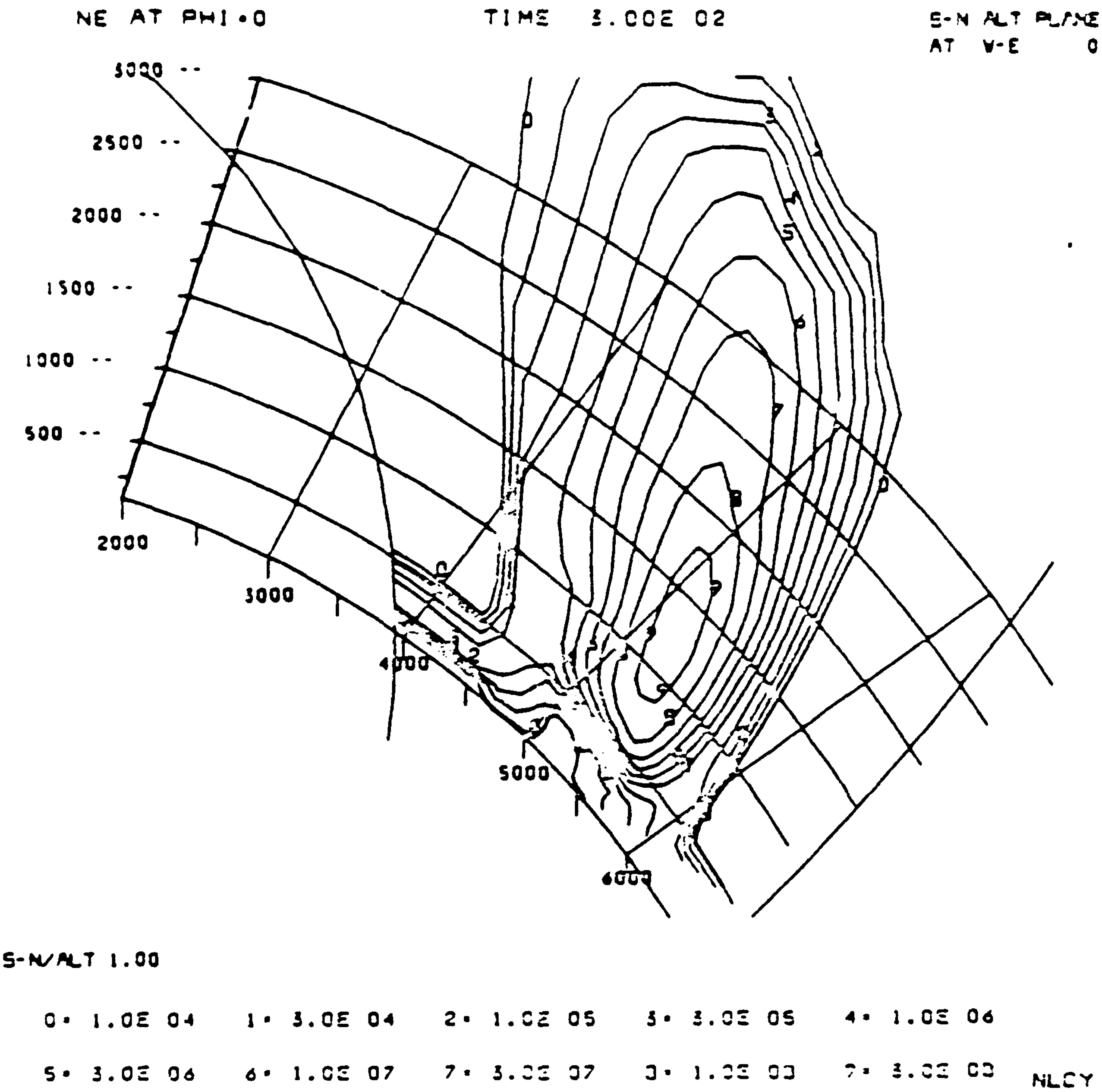

Figure 4. A contour plot of initial condition electron densities at 300 seconds on the northern conjugate central, meridion plane. Contour levels in electrons cm^{-3} are shown at the bottom of the graph.

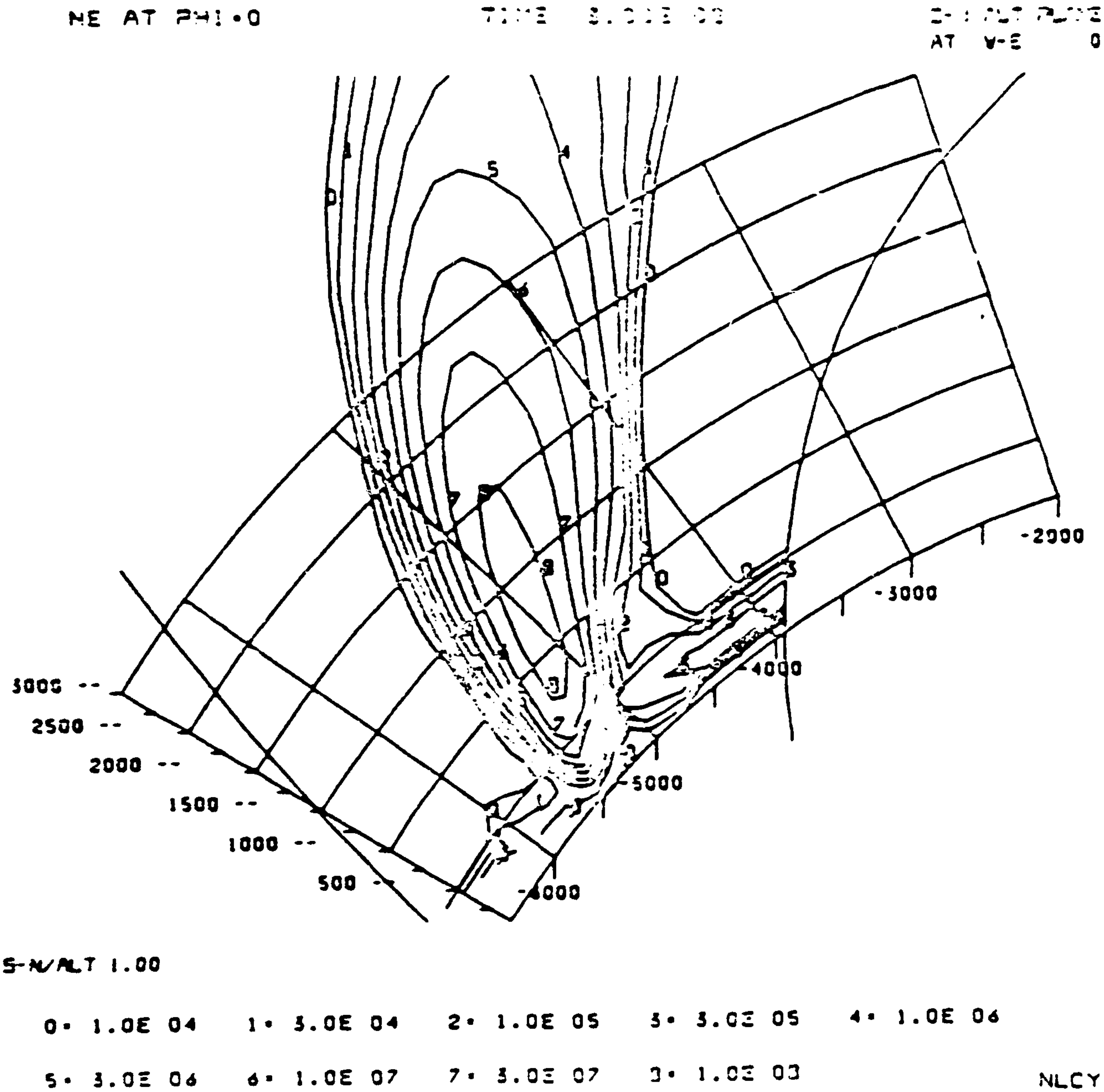

Figure 5. A contour plot of initial condition electron densities at 300 seconds on the southern conjugate central meridional plane. Contour levels in electrons cm^{-3} are shown at the bottom of the graph.

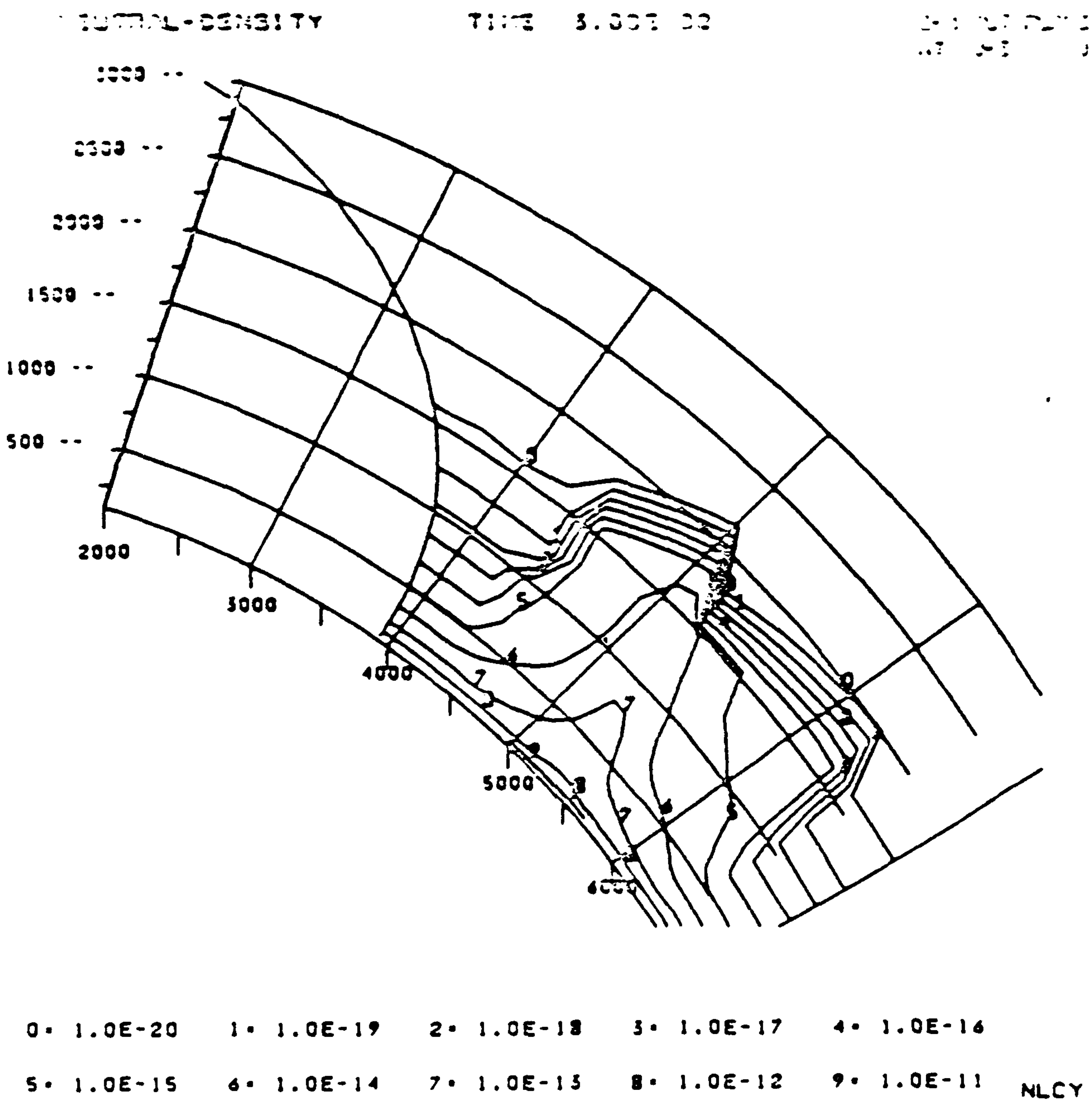

Figure 6. A contour plot of initial conditions neutral atmospheric density at 300 seconds on the northern conjugate central meridion plane. Contour levels are shown in gauss cm^{-3} at the bottom of the graph. The sharp cutoff in atmospheric density above 1500 kilometers altitude is caused by the termination of the MICE/MELT neutral atmosphere numerical mesh.

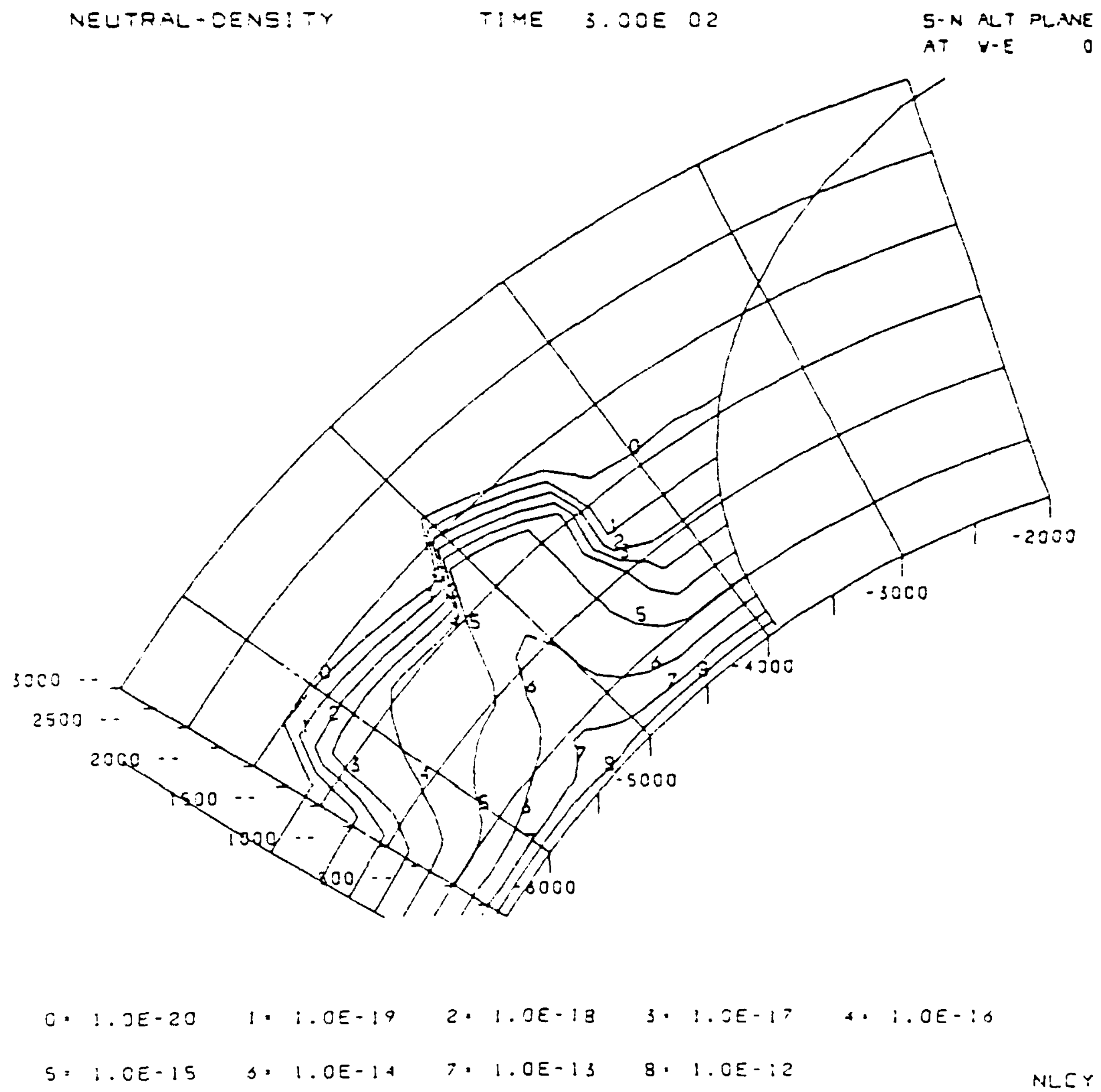

Figure 7. A contour plot of the initial condition neutral atmospheric density at 300 seconds on the southern conjugate central meridion plane. Contour levels are shown in gauss cm^{-3} at the bottom of the graph.

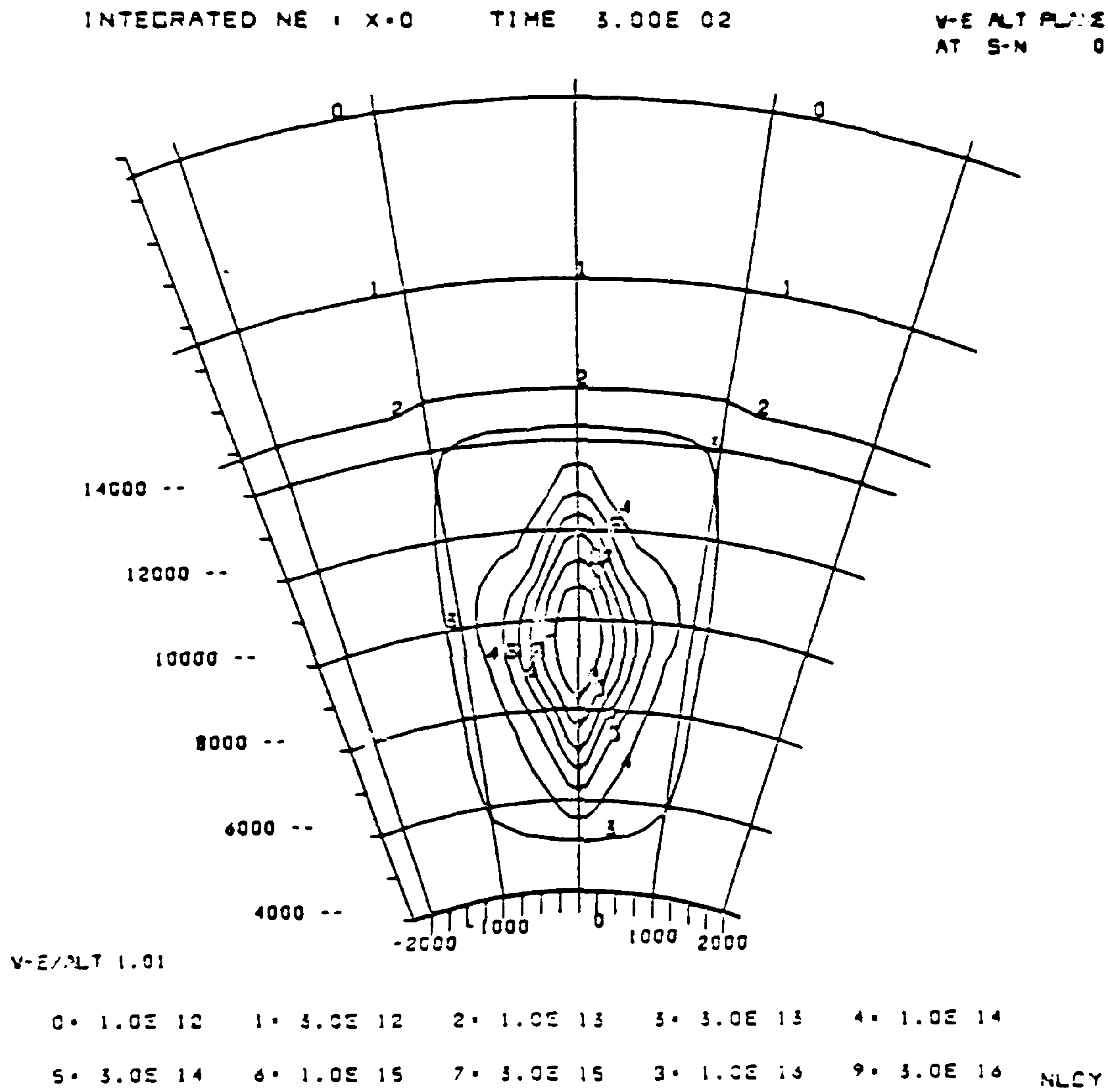

Figure 8. A contour plot of the field line integrated electron density at 300 seconds on the geomagnetic equatorial plane. Contour levels, shown at the bottom of the plot, are in electrons cm^{-2}. The vertical scale is kilometer altitude and the horizontal scale is kilometers longitude at the earth's surface.

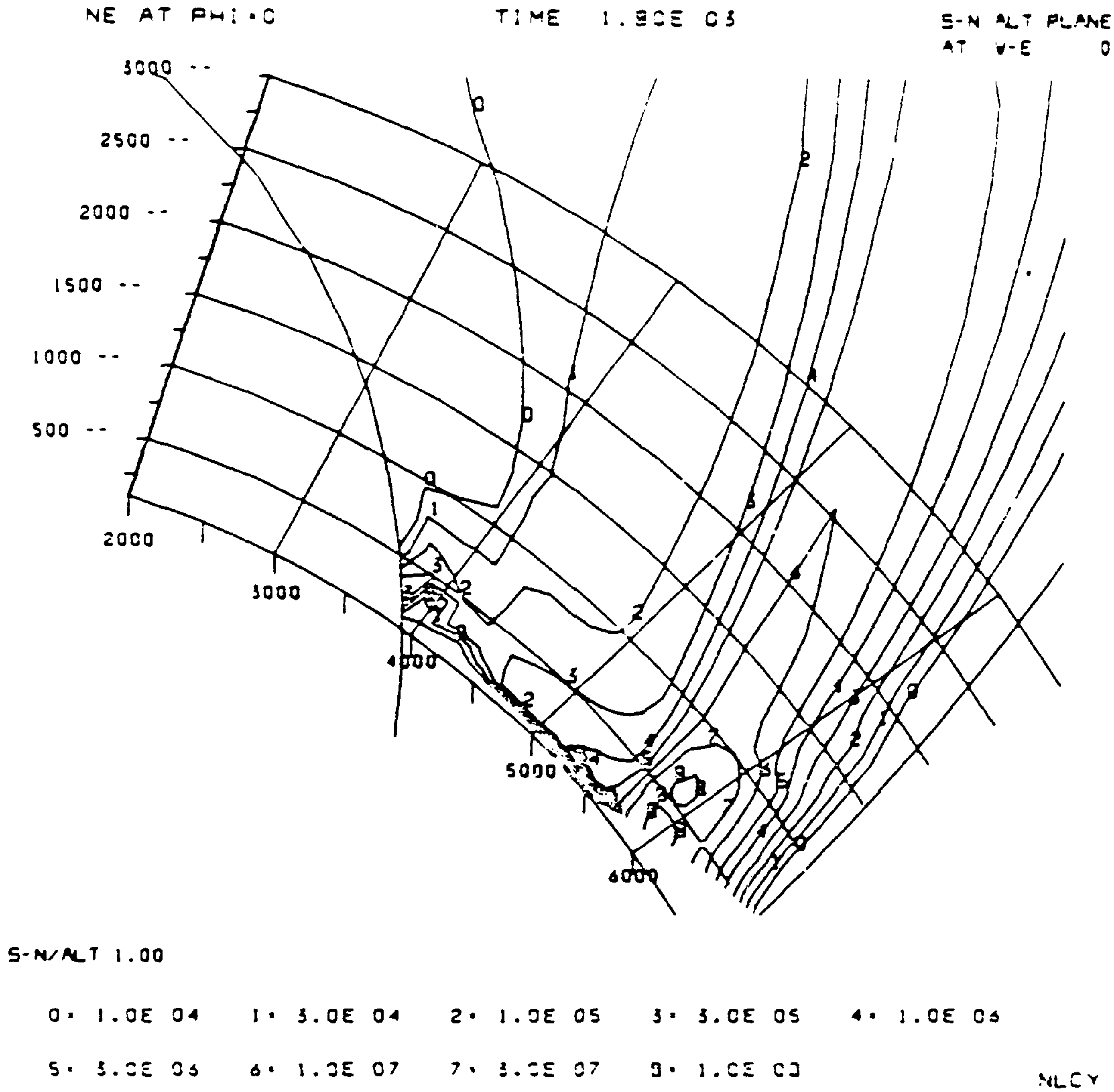

Figure 9. A contour plot of the electron density in the northern conjugate central meridion plane at 1300 seconds from the DEMAG simulation. Note the northward motion of the plasma plume relative to its location at 300 seconds in Figure 4. The plasma densities have also fallen by about a factor of 3 at the lower altitudes.

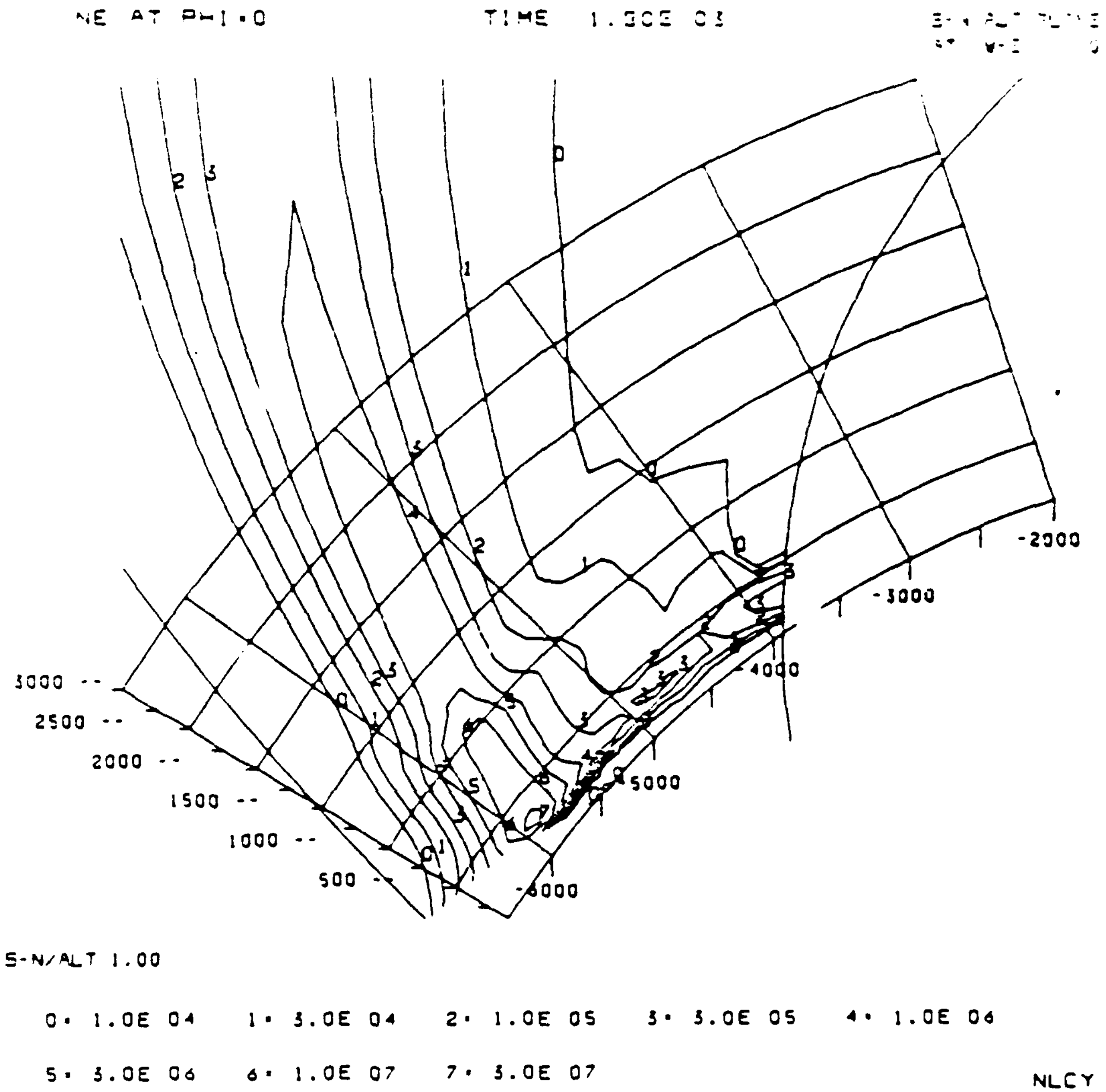

Figure 10. A contour plot of the electron density in the southern conjugate central meridion plane at 1800 seconds from the DEMAG simulation. We again notice the poleward motion and the reduction of plasma density at low altitudes.

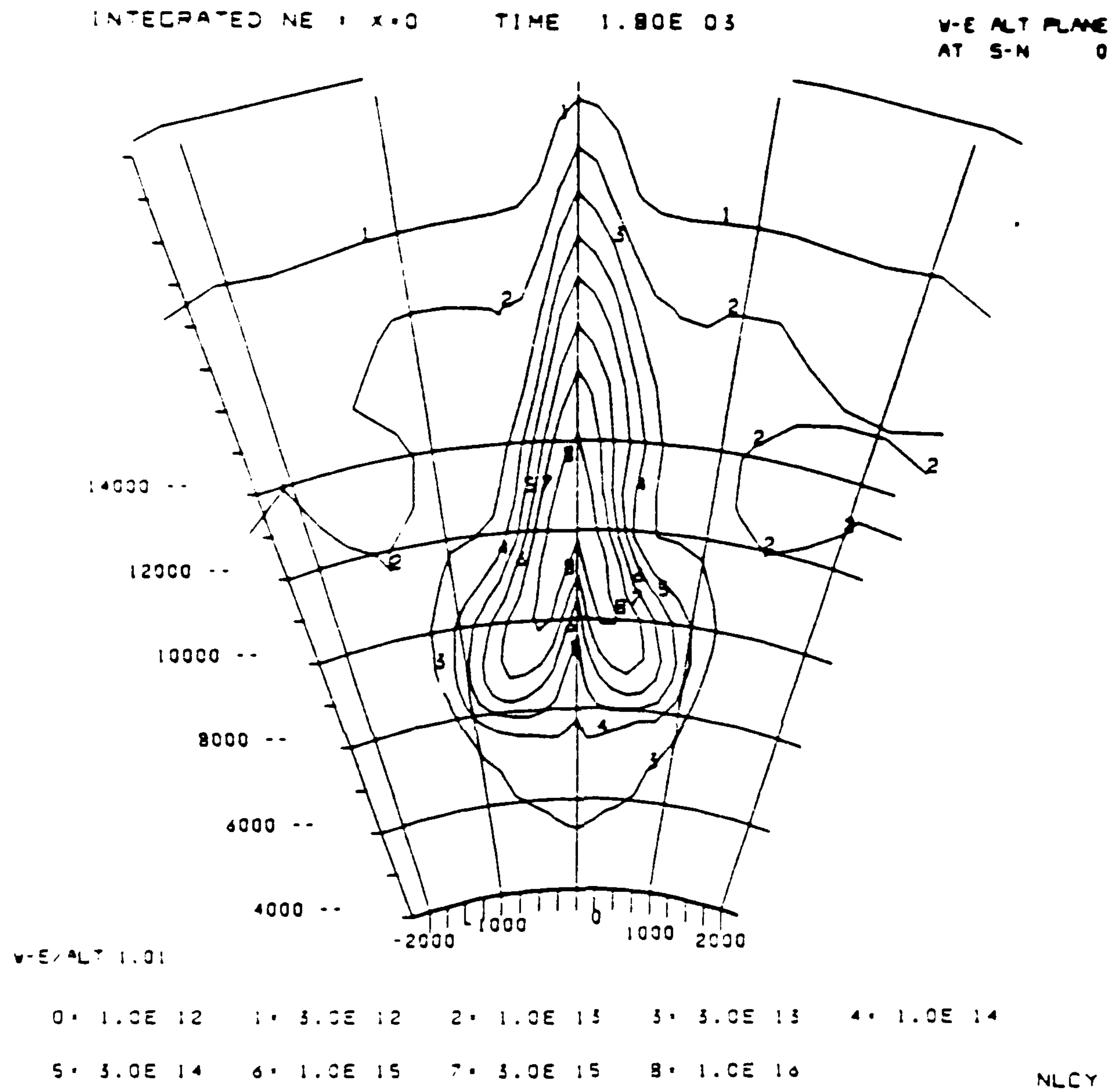

Figure 11. A contour plot of the field line integrated electron density in the geomagnetic equatorial plane at 1800 seconds from the DEMAG simulation. In comparing this plot to Figure 8 we note that the central portion of the plasma plume has moved dramatically upward and poleward. However, the eastward and westward portions of the plume have moved very little.

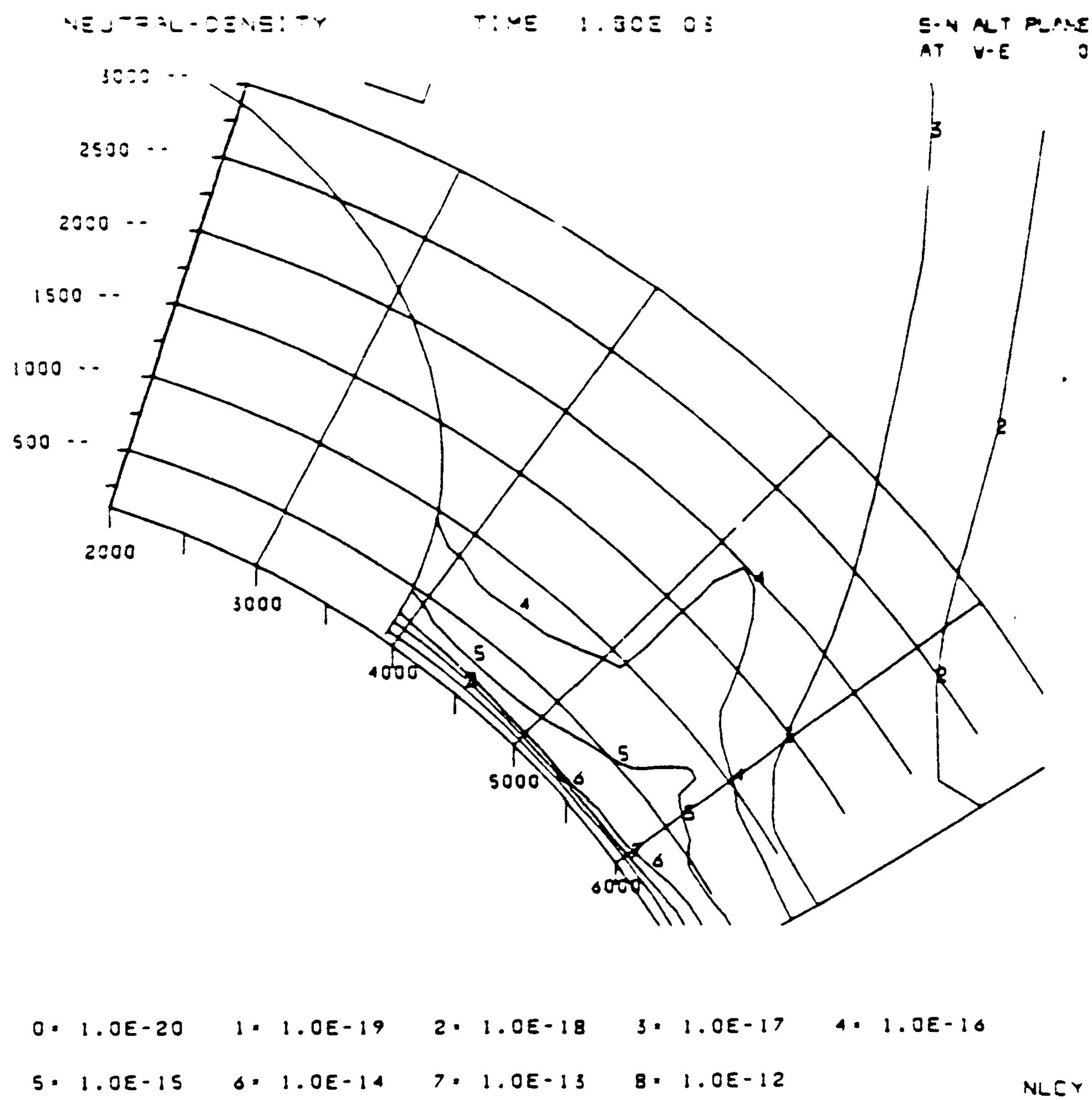

Figure 12. A contour plot of the neutral atmospheric density in the northern conjugate central meridion plane at 1800 seconds from the DEMAG simulation. By this time the neutral atmospheric density has almost returned to its ambient values.

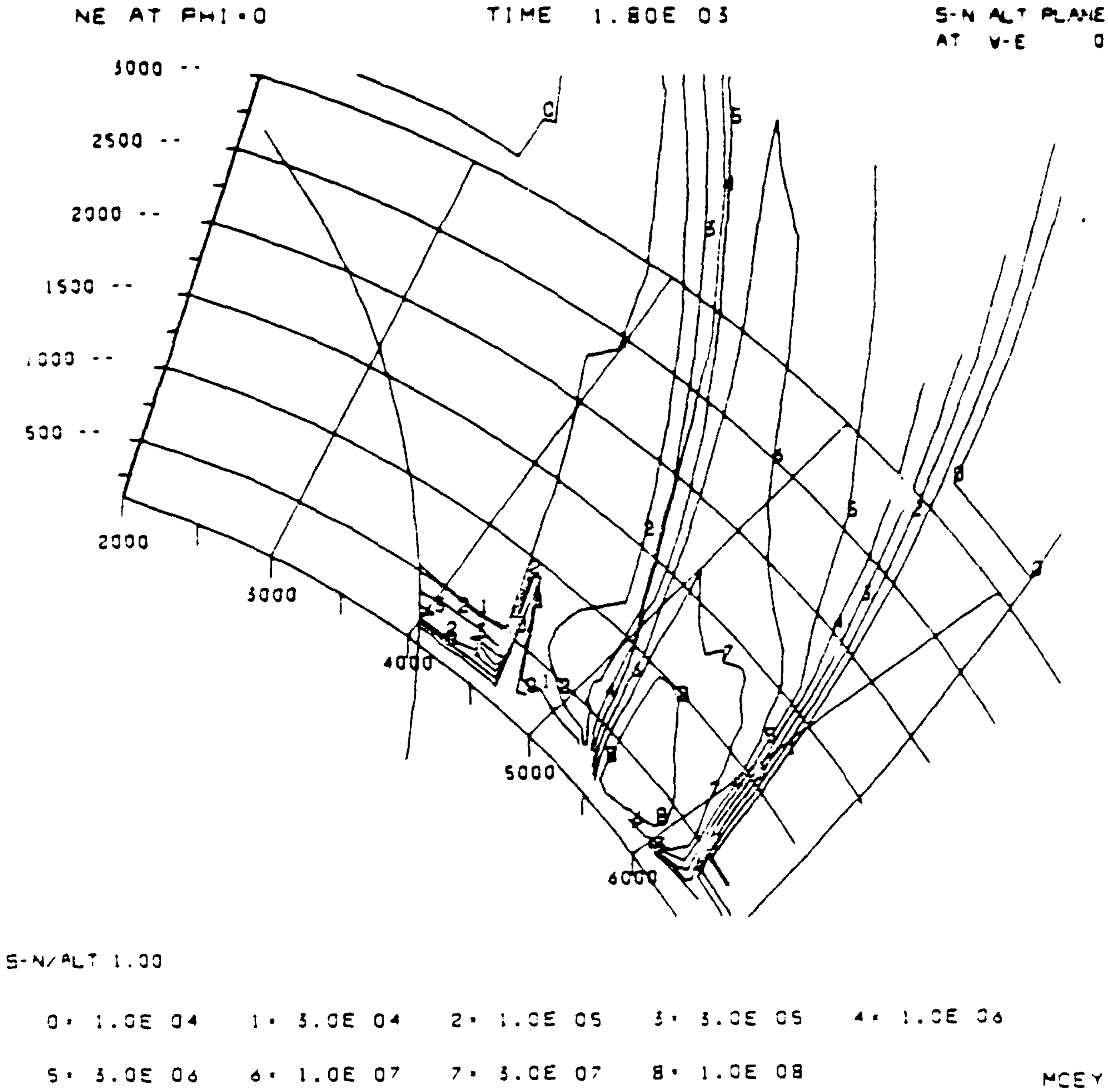

Figure 13. A contour plot of the electron density from the MELT simulation in the northern conjugate central meridion plane at 1800 seconds. These results are to be compared to the DEMAG results in Figure 9.

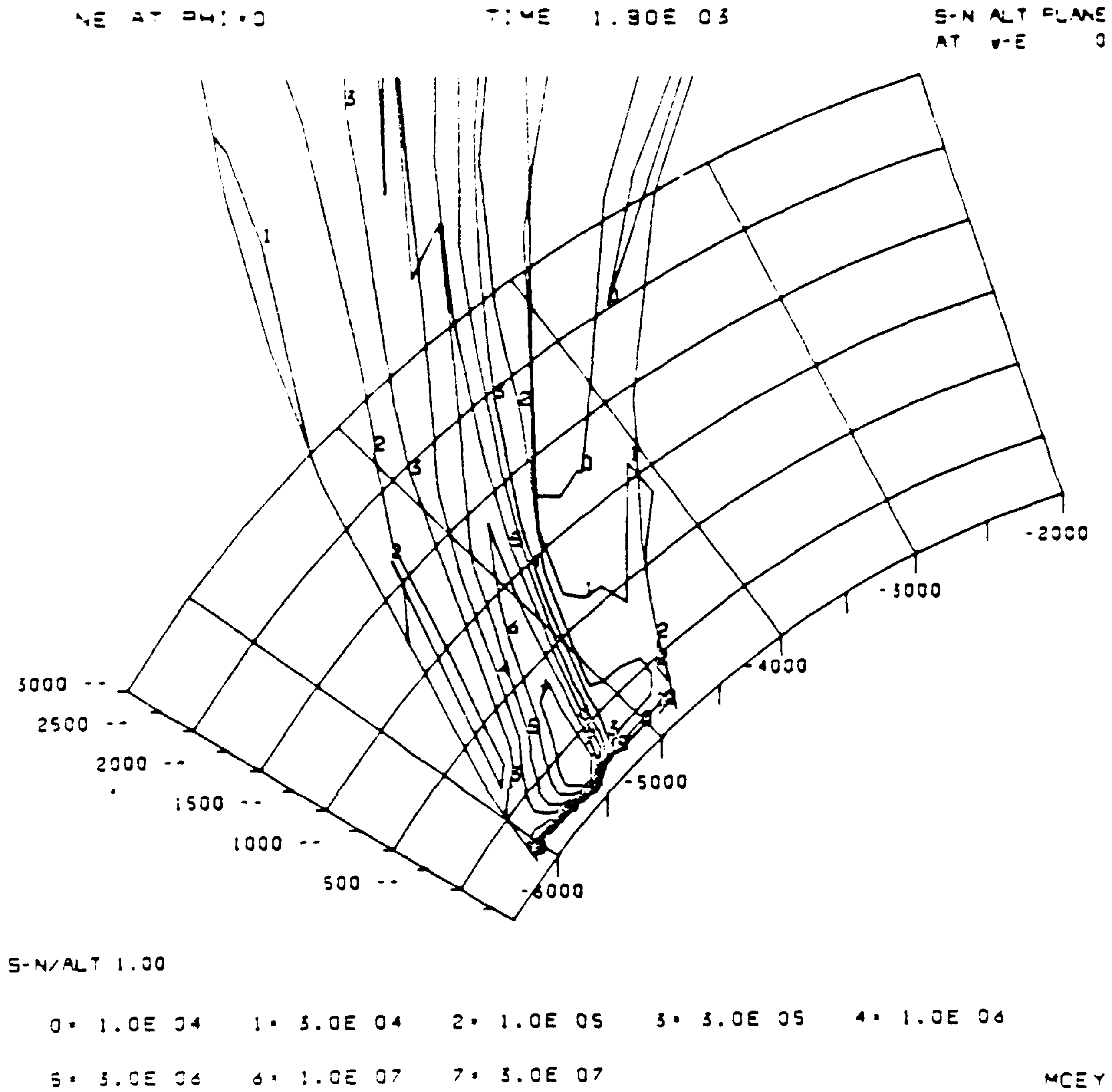

Figure 14. A contour plot of the electron density from the MELT simulation in the southern conjugate central meridion plane at 1800 seconds. These results are to be compared to the DEMAG results in Figure 10.

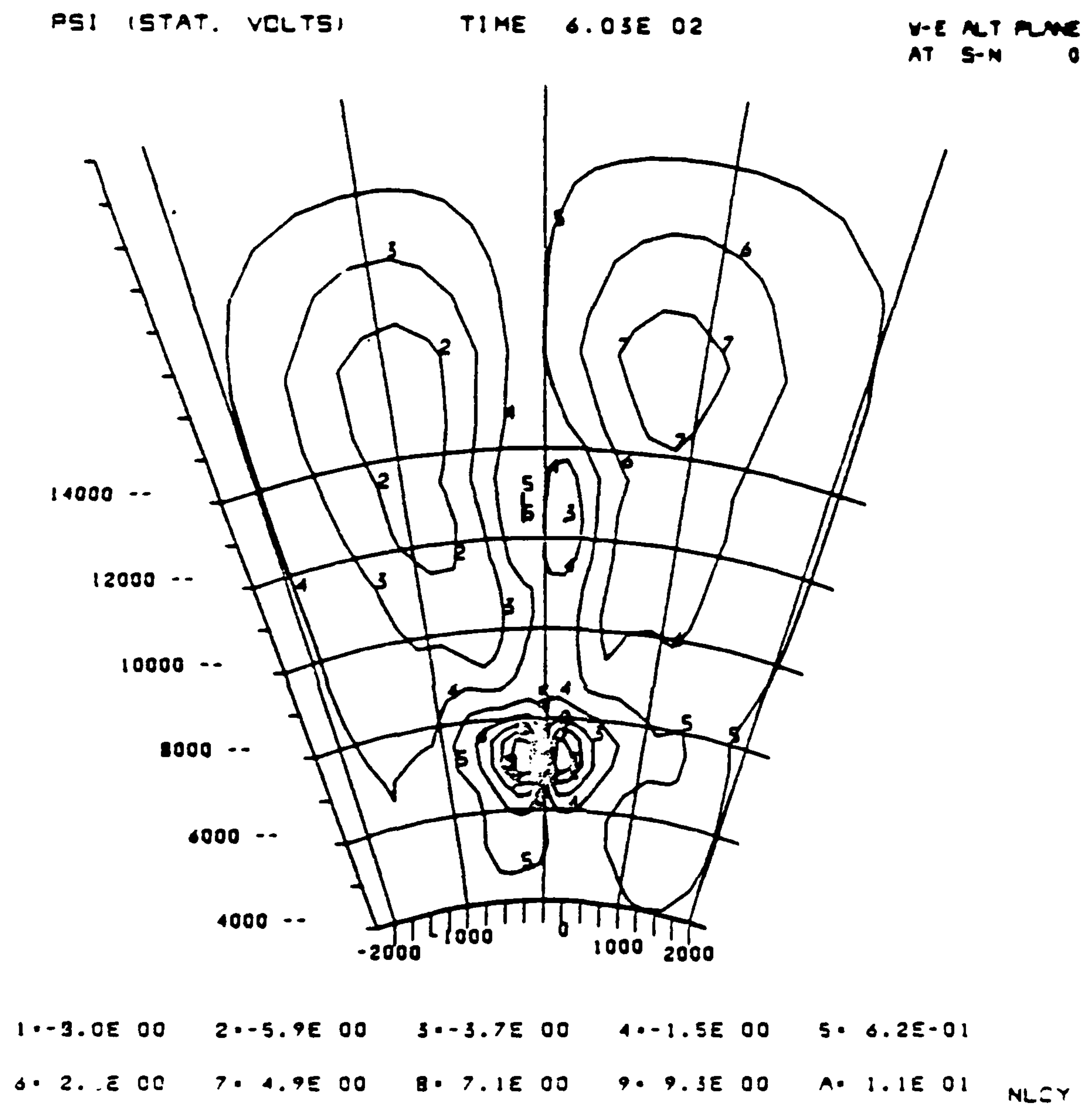

Figure 15. A contour plot of the electrostatic potential at 600 seconds for the DEMAG simulation shown on the geomagnetic equatorial plane. The contour levels are shown at the bottom of the diagram for the potential and are in stat volts. See text for a discussion of the results.

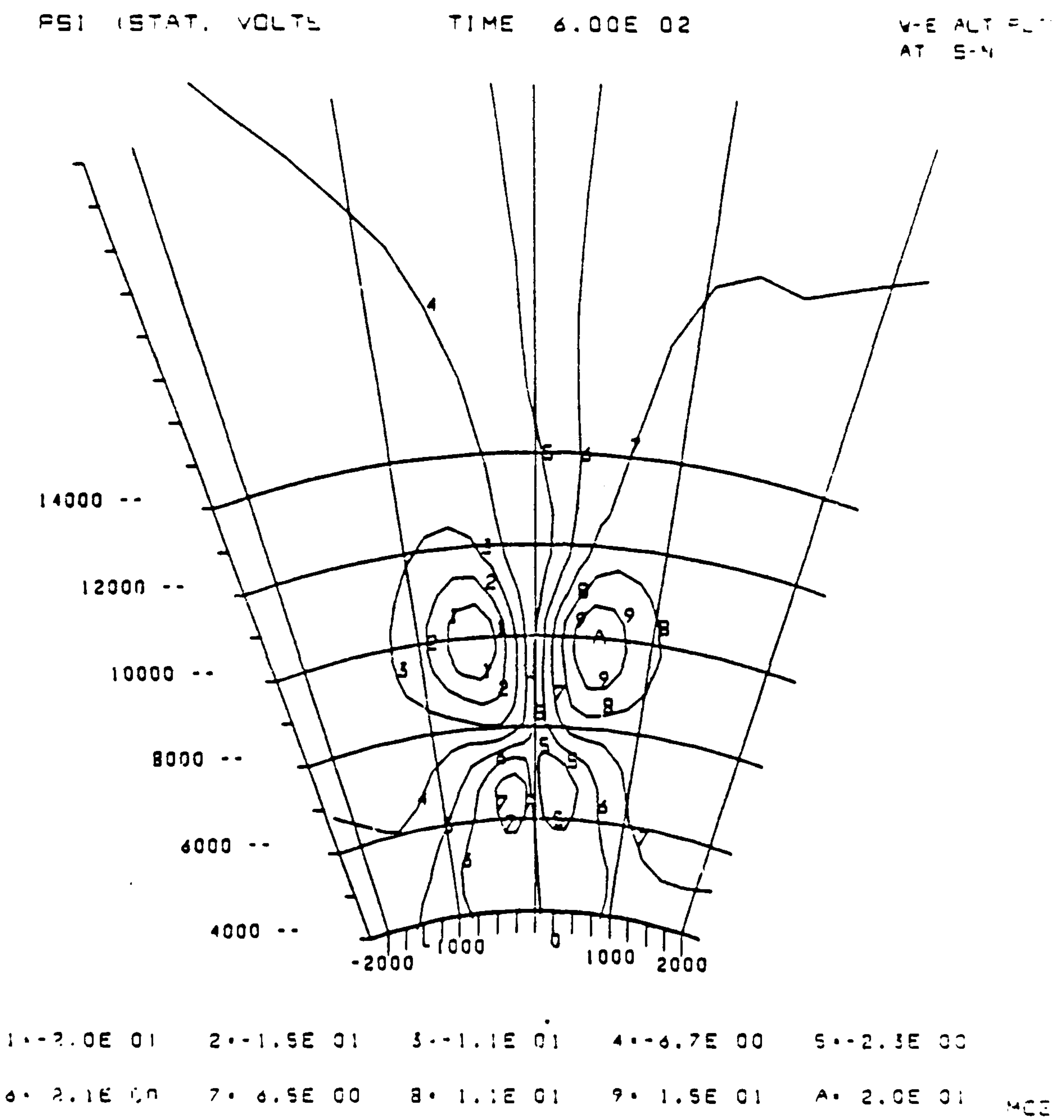

Figure 16. A contour plot of the electrostatic potential at 600 seconds for the MELT simulation shown on the geomagnetic equatorial plane. The contour levels are shown at the bottom of the diagram for the potential in stat volts.

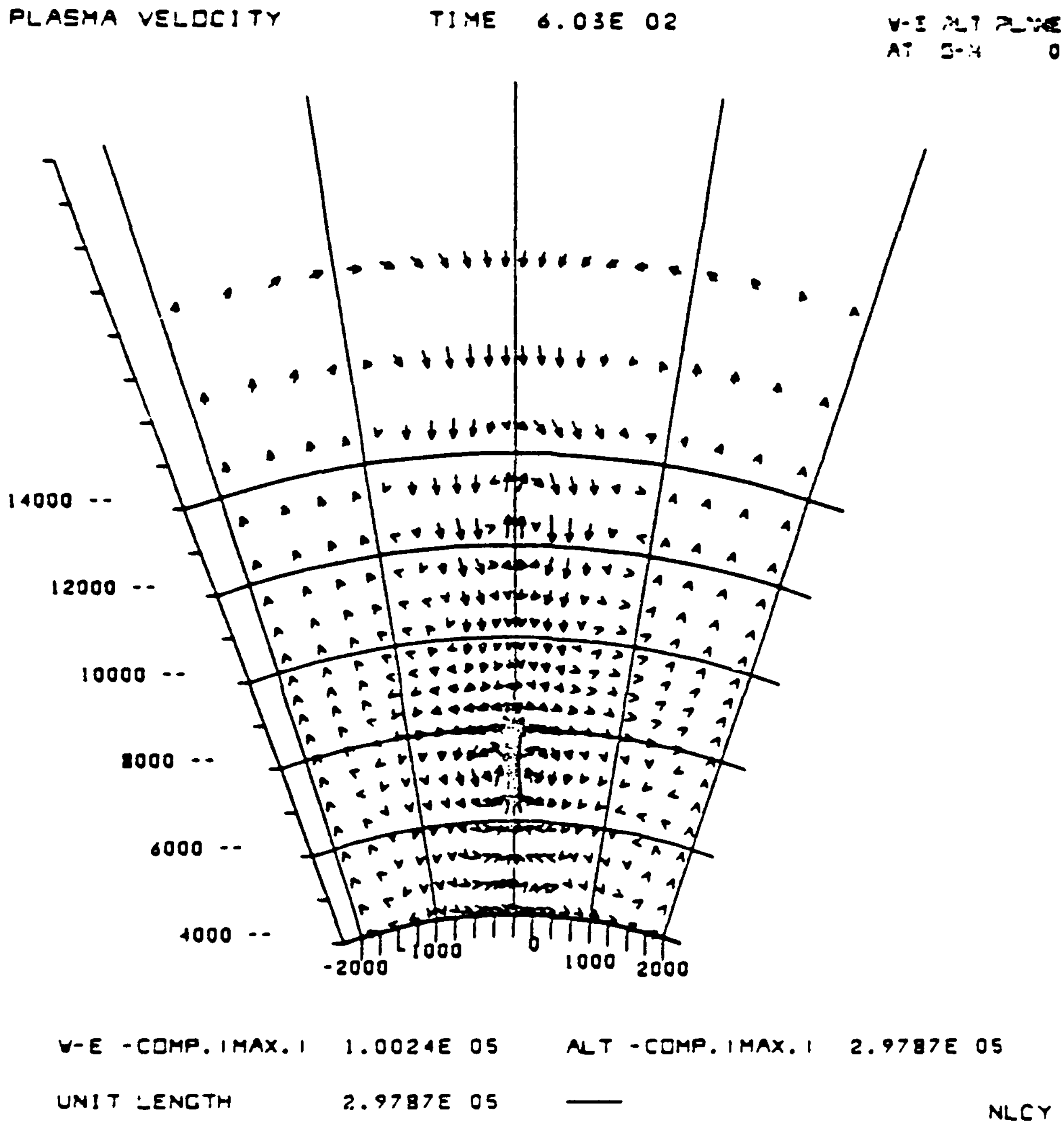

Figure 17. A vector plot of the velocity perpendicular to the geomagnetic field in the equatorial plane for the DEMAG simulations at 600 seconds. The velocity scale is shown at the bottom in cm sec^{-1}. See text for a discussion.

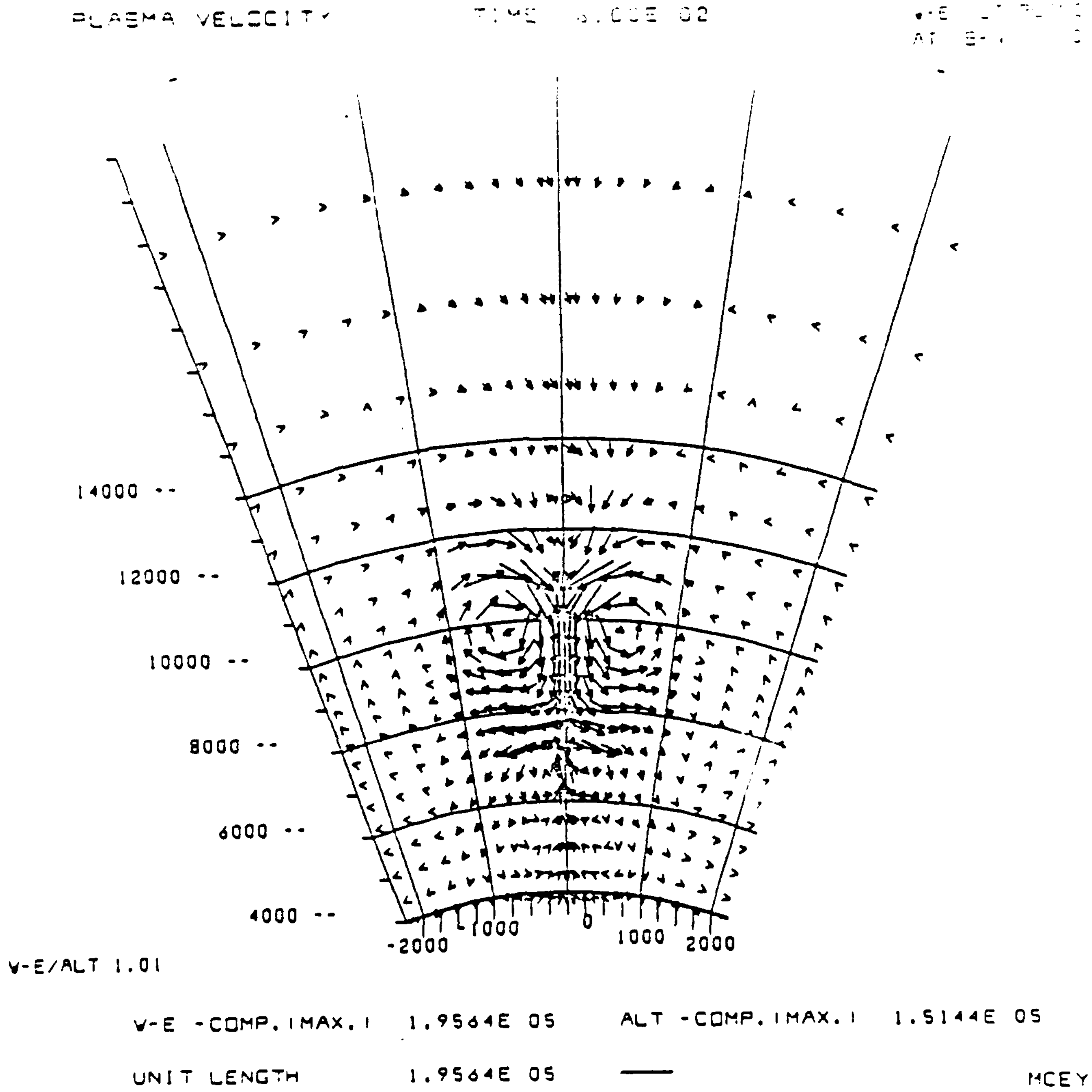

Figure 18. A vector plot of the velocity perpendicular to the geomagnetic field in the equatorial plane for the MELT simulation at 600 seconds. The velocity scale is shown in cm sec^{-1}.

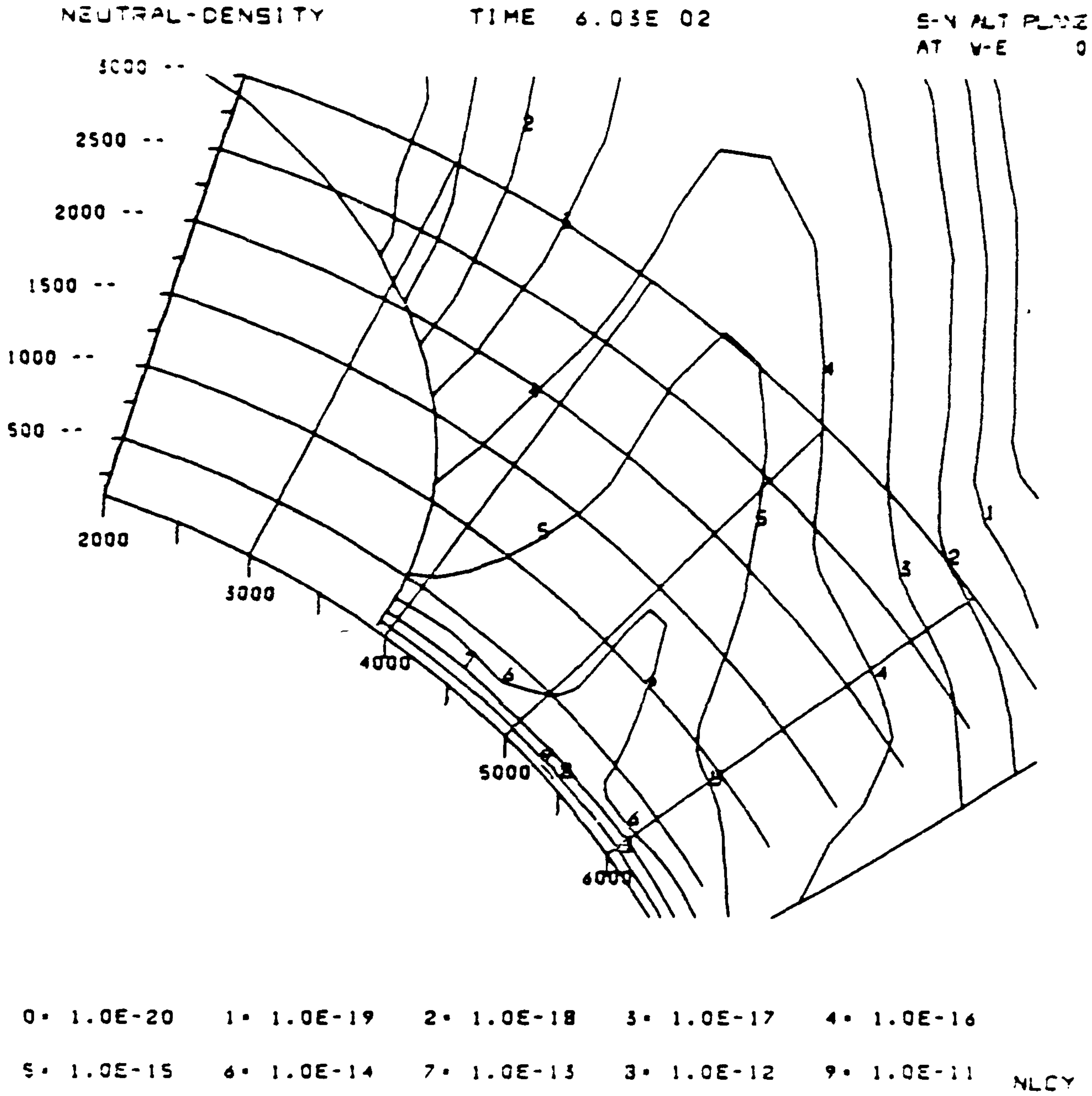

Figure 19. A contour plot of the neutral atmospheric density in the northern conjugate central meridion plane for the DEMAG simulation at 600 secs. Notice the high densities above 1500 km altitude which are not considered in the MELT simulation.

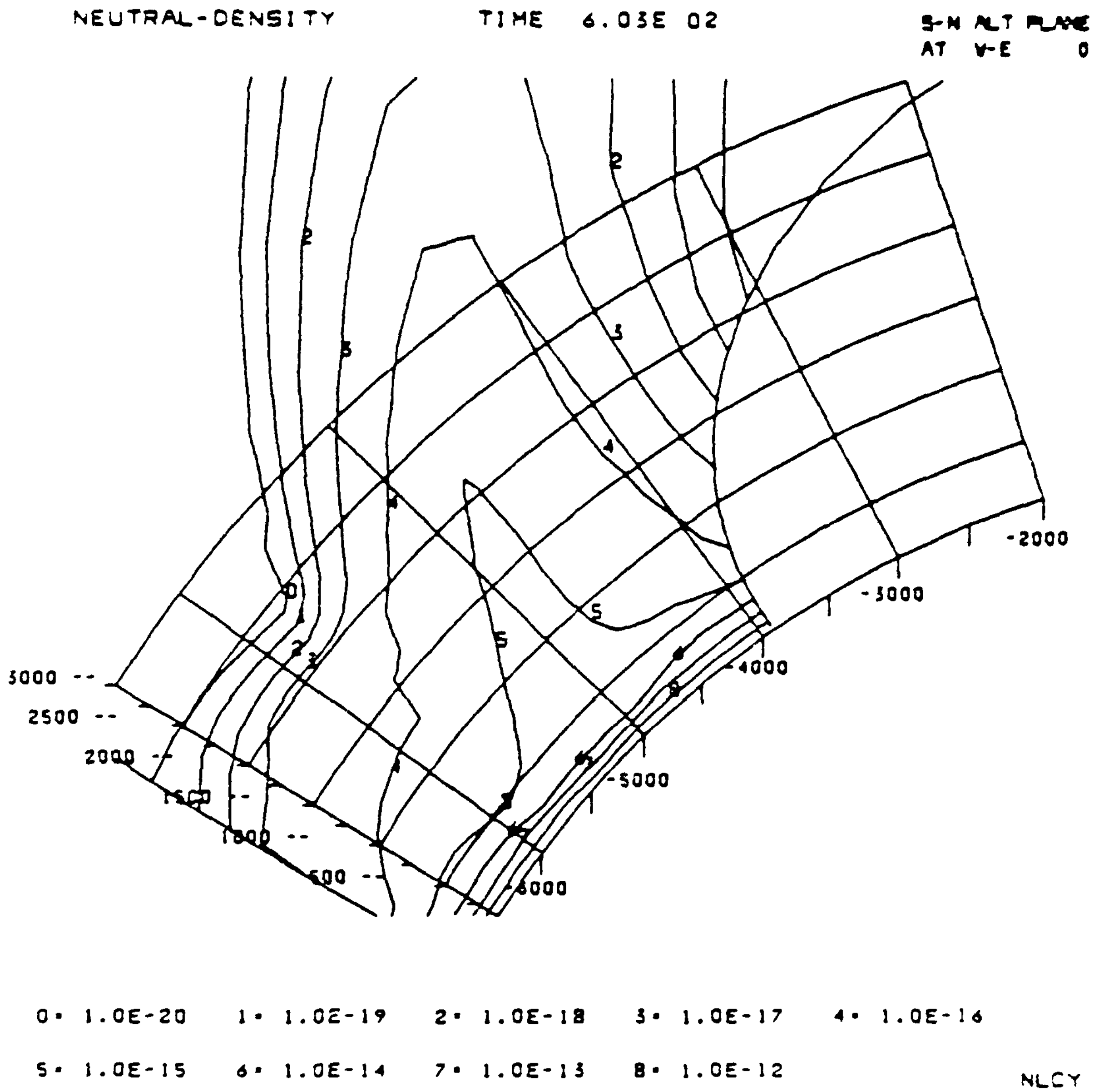

Figure 20. A contour plot of the neutral atmospheric density in the southern conjugate central meridion plane for the DEMAG simulation at 600 secs. Similar comments to those for Figure 19 apply.

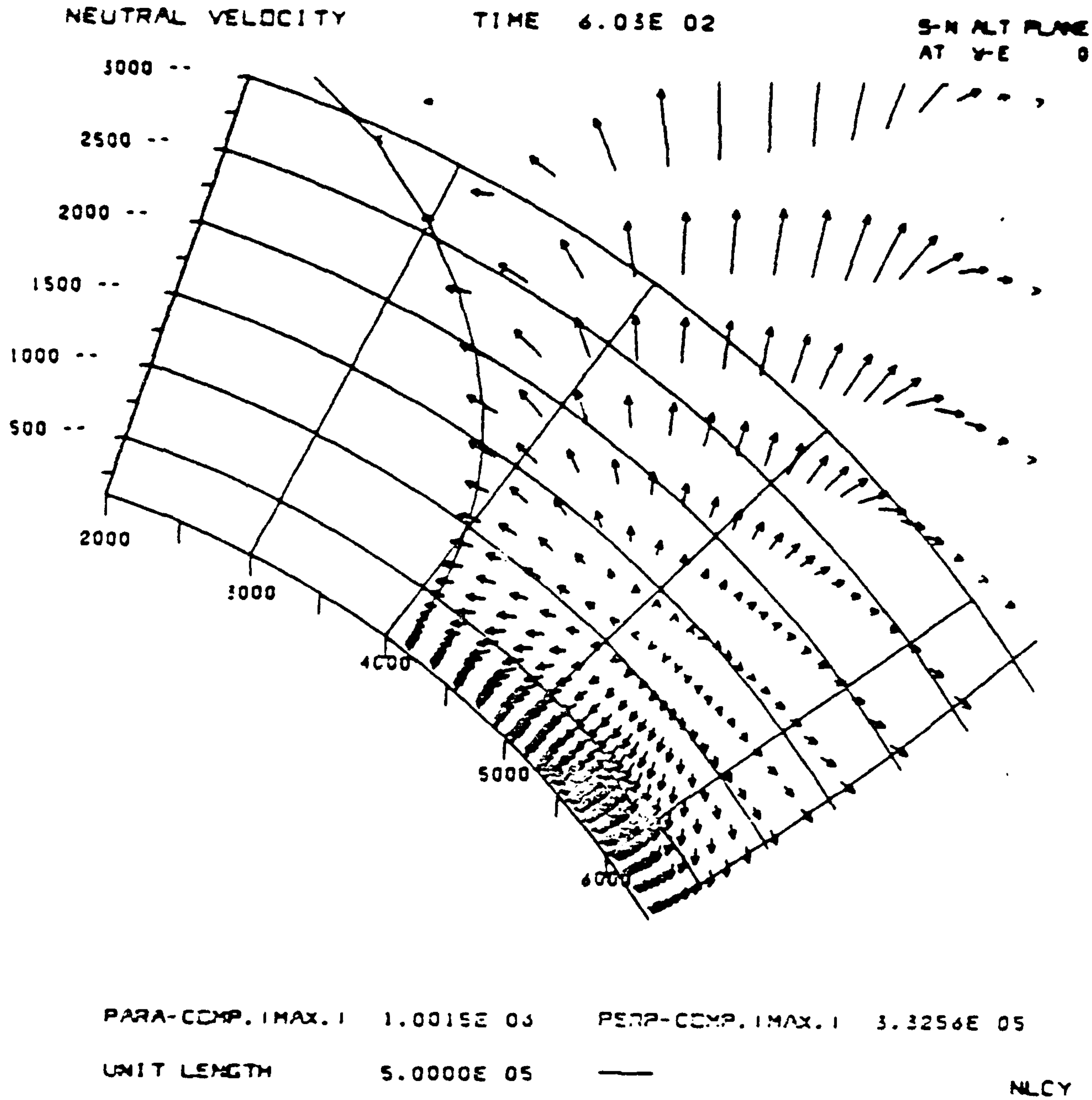

Figure 21. A vector plot of neutral velocity for the DEMAG simulation in the northern conjugate central meridion plane at 600 seconds. Notice the large upward and poleward, relative to the geomagnetic field, velocities at altitudes above 1500 kilometers.

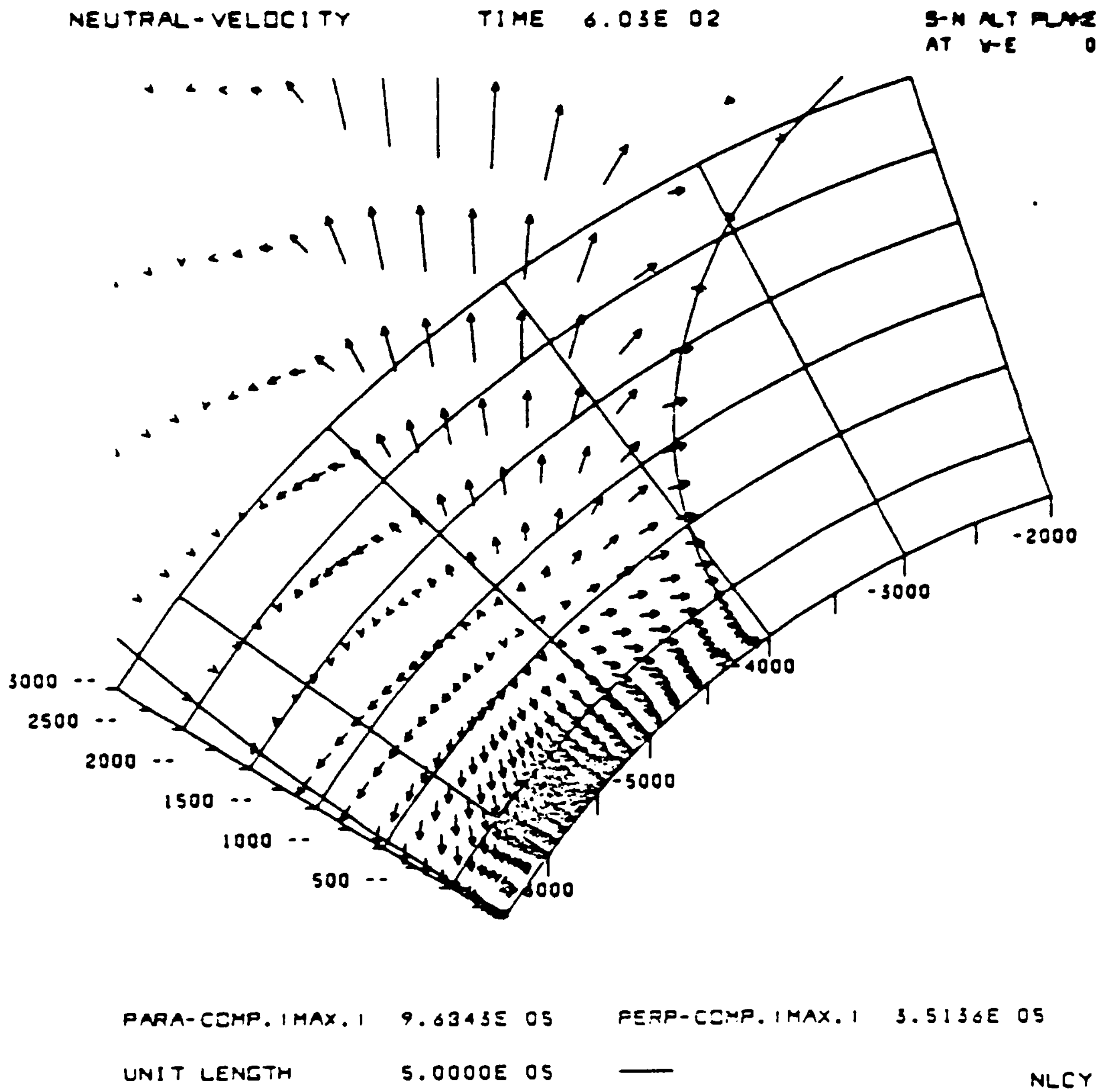

Figure 22. A vector plot of neutral velocity for the DEMAG simulation in the southern conjugate central meridion plane at 600 seconds. Comments similar to those for Figure 21 apply.

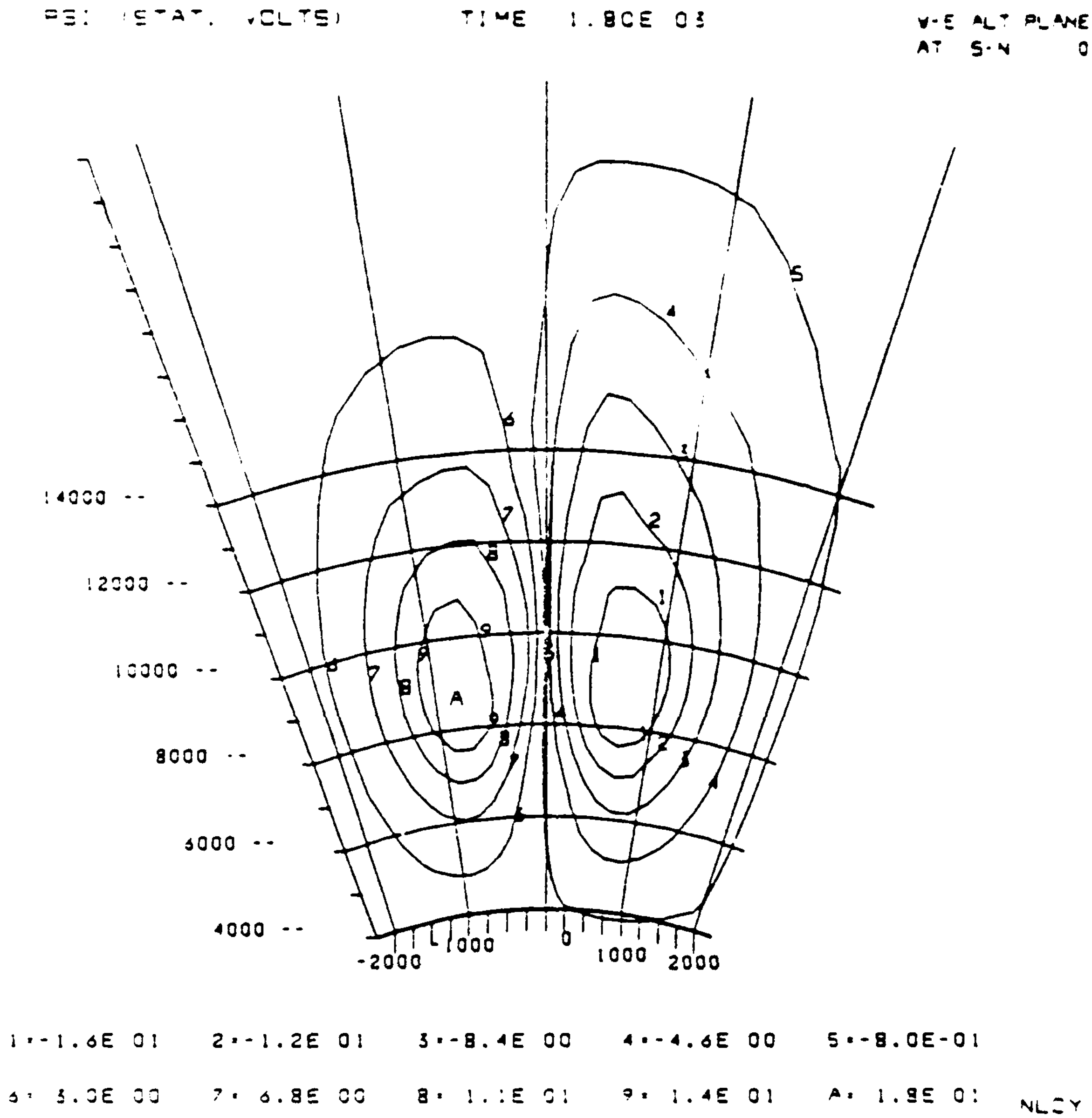

Figure 23. A contour plot of the electrostatic potential for the DEMAG simulation in the geomagnetic equatorial plane at 1800 seconds. Refer to the text for discussion.

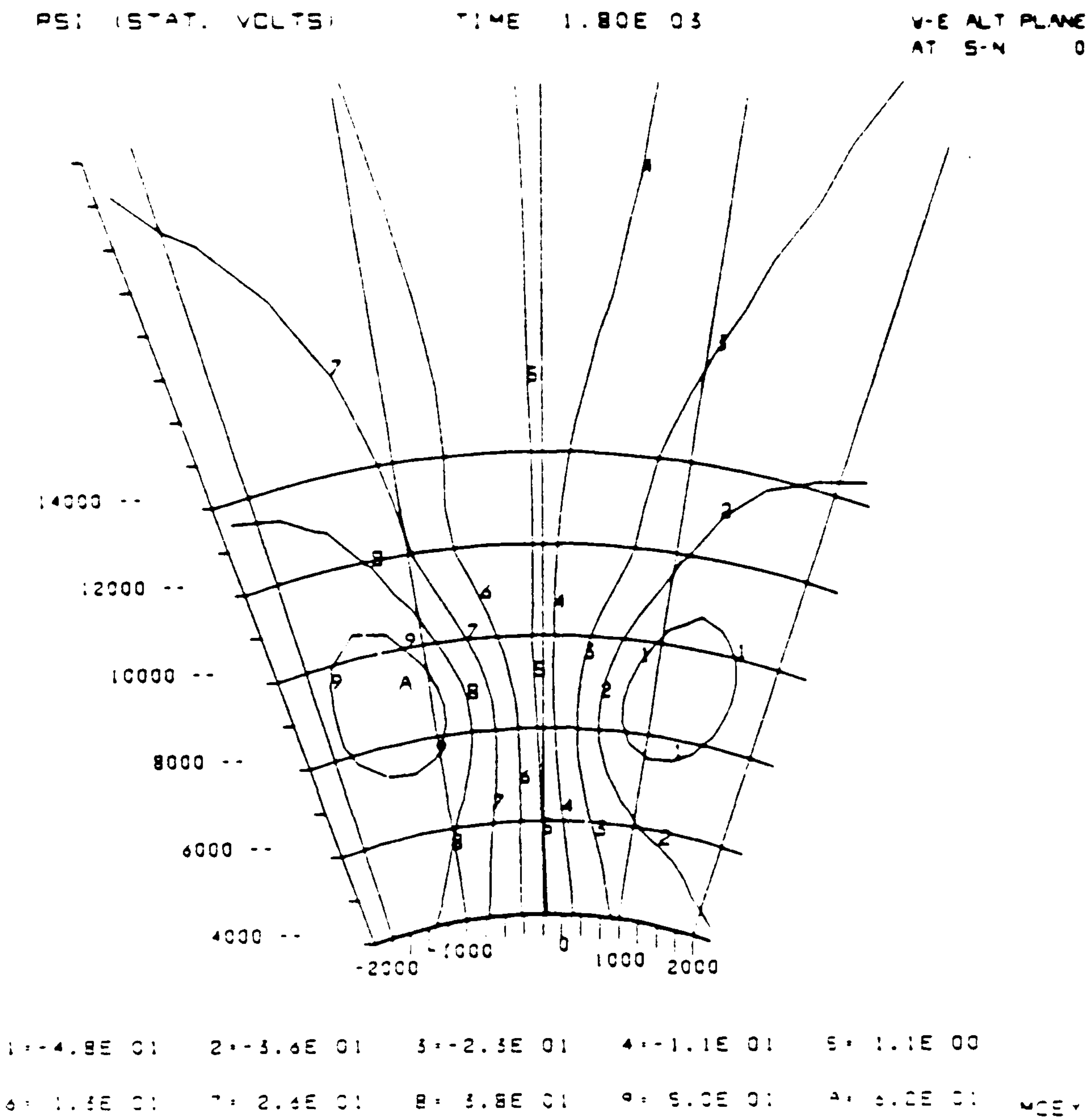

Figure 24. A contour plot of the electrostatic potential for the MELT simulation in the geomagnetic equatorial plane at 1800 seconds.

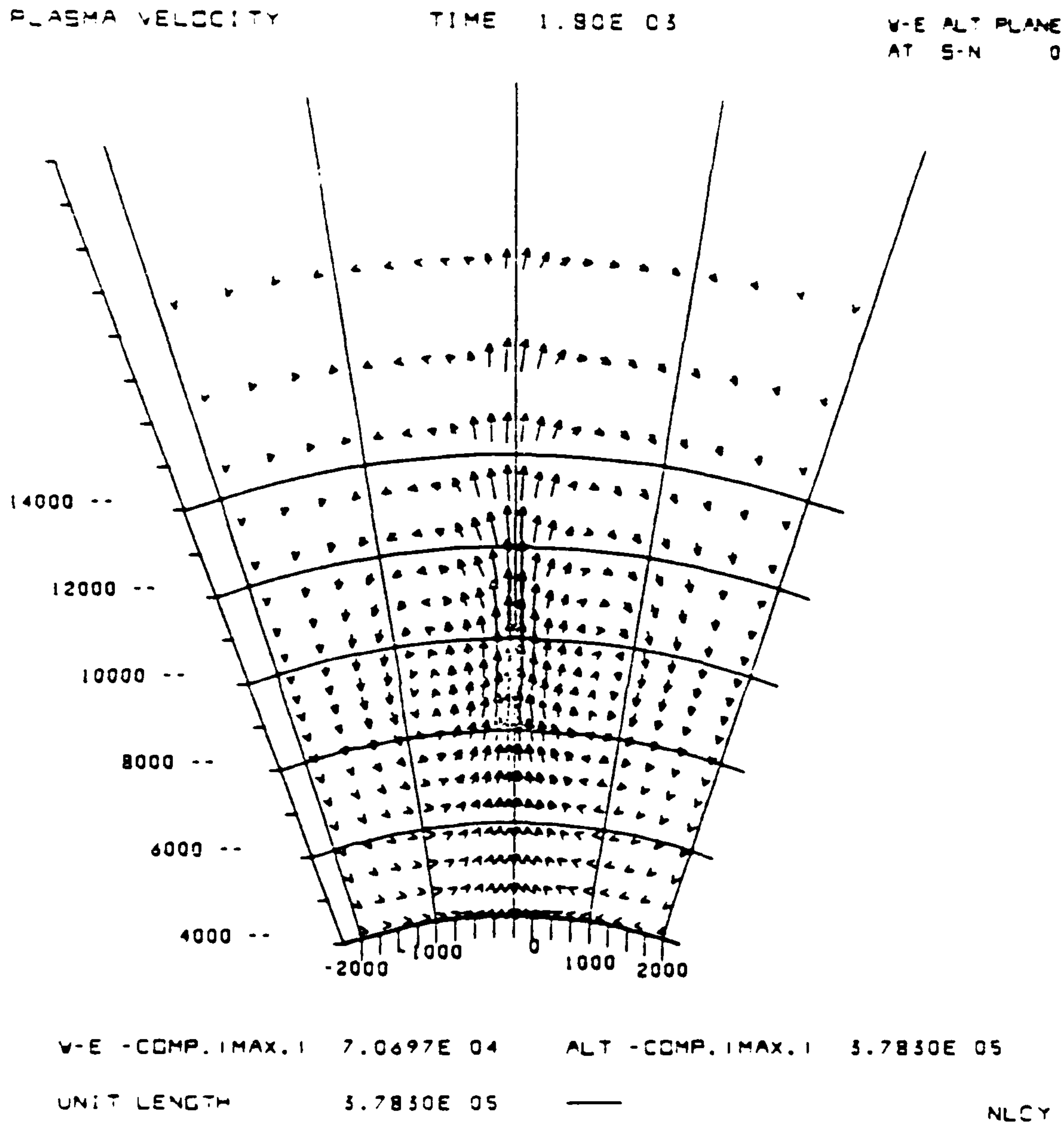

Figure 25. A vector plot of perpendicular velocities in the geomagnetic equatorial plane for 1800 seconds from the DEMAG simulation. Refer to the text for discussion.

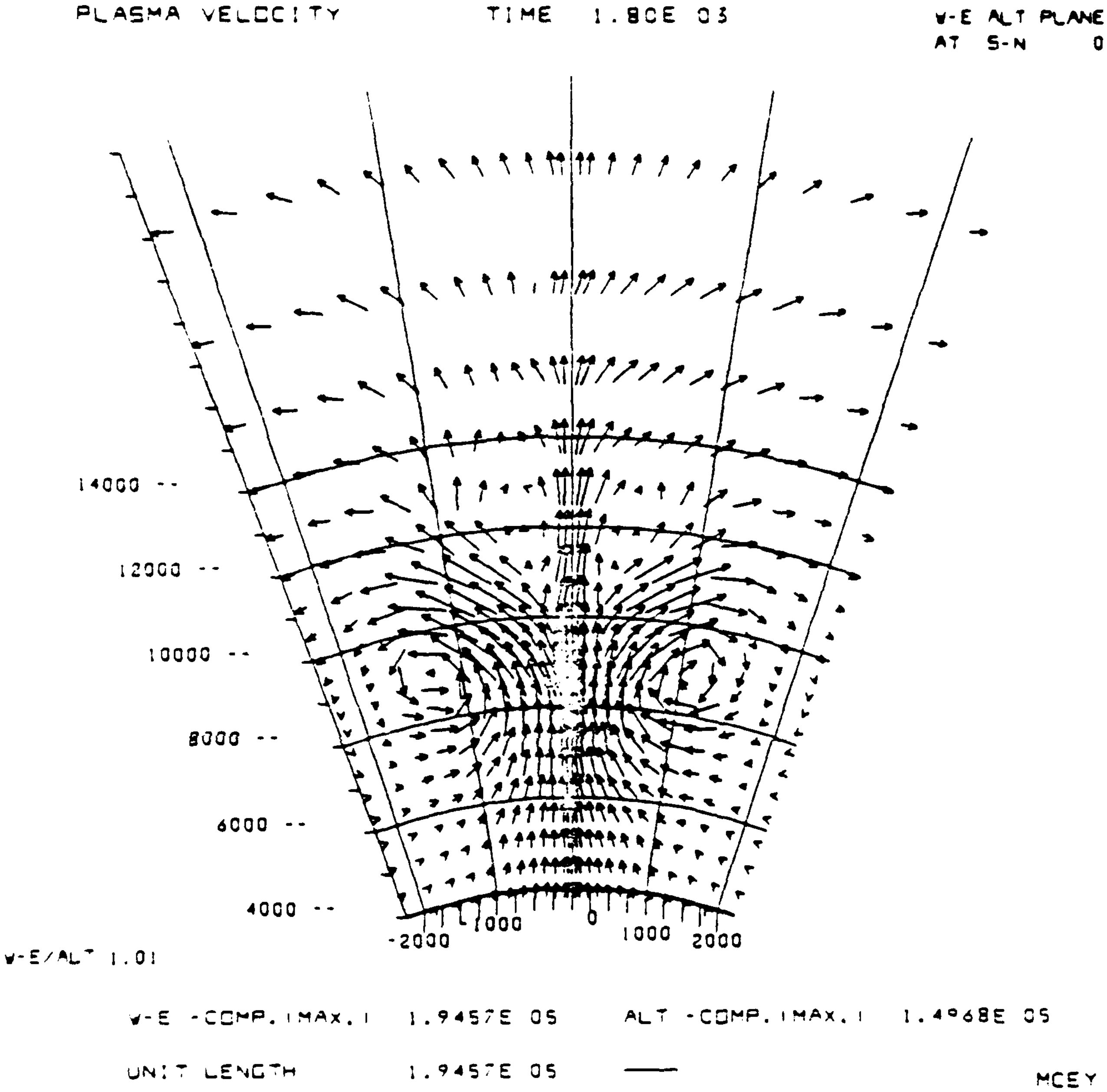

Figure 26. A vector plot of perpendicular velocities in the geomagnetic equatorial plane for *1800* seconds from the MELT simulations.

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